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MONTANA COMMERCIAL SECTOR STUDY APPROACH

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MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

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Conservation Potential in the Montana Commercial Sector: Methodology Discussion and Overview

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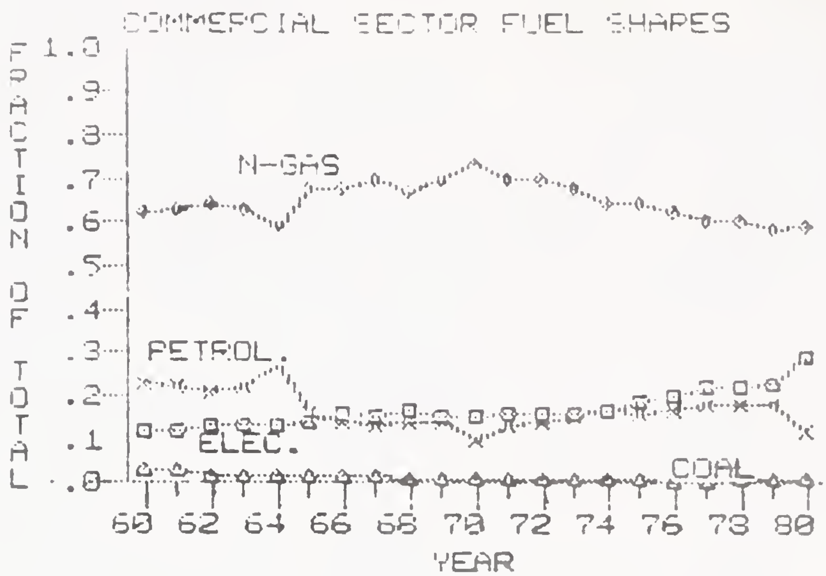
I. EXISTING DATA

Overview of Commercial Sector Consumption

The activities of the Montana commercial sector are exceedingly diverse; the types of buildings, and their energy consumption, vary greatly. At best estimate, the sector accounted for about 42.6 x 10^{12}Btus or 15 percent of the total energy demand in Montana in 1980 (DOE, 1982). The annual growth rate of energy demand in the sector over the last twenty years has been 2.1 percent. Natural gas currently accounts for about 60 percent of the sector's energy demand, oil for 10 percent and electricity for 30 percent. The increase in consumption of electricity -- 5.6 percent annually over the last twenty years -- has been much more rapid than that of the aggregate demand for energy. Since the 1973 oil embargo the annual growth rate for electricity has been even greater, over 7.2 percent per year (DOE, 1982). Figure 1 depicts how the Montana commercial sector fuel mix has changed over the period 1960-1980. (All data is based on consumption in the commercial sector as defined by utilities.)

Figure 1



The proportion of energy use in Montana's commercial sector for space heating is greater than that found in national studies, while the use for cooling is less. Jackson (1978) found 43 percent and 21 percent of all U.S. commercial energy was used for heating and cooling, respectively. Tables 1 and 2 (Ecotope 1977) contain available state level estimates of the energy used for five end uses and four fuel types.

Table 1
Energy End Use in the Montana Commercial Sector, 1976

End Use	10^9 Btu	Percent of Total
Space Heat	14.6	49.5
Cooling	3.8	12.9
Lighting	8.2	27.8
Water Heat	.5	1.7
Other*	2.4	8.2

Table 2
Energy End Use in the Montana Commercial Sector by Fuel, 1976

End Use	Electricity	Gas	Fuel Oil	LPG
Space Heat	1.0%	68.9%	96.7%	66.7%
Cooling	5.9%	21.6%	0.0%	0.0%
Lighting	80.4%	0.0%	0.0%	0.0%
Water Heat	1.0%	2.7%	0.0%	0.0%
Other*	11.7%	6.8%	3.3%	33.3%

*Represents electrical equipment, refrigeration and food preparation.

Source: Ecotope, 1977. "Commercial Energy Conservation," Working Paper #2, Montana Research and Development Institute, Butte, Montana.

Size and Scope of the State Commercial Sector

A study of utilities in Montana estimated the utilities served 47,000 commercial accounts; 29,300 were served by Montana Power Company (MPC) (Cartwright, 1982). Table 3 lists the number of commercial sector accounts.

Table 3
1981 Commercial Sector Electrical Accounts in Montana

Utility	# of Accounts	Sales (Average MW)
Montana Power	29,300	160
Pacific Power & Light	3,710	16
Montana Dakota Utility	3,890	36
Western G&T	5,580	17
Central G&T	3,100	8
Upper Missouri	1,800	3
TOTAL	47,380	240

Source: Paul Cartwright, August 1, 1982. Personal Conversation.

These figures are misleading in that utilities often classify customers by size of load, so that industrial firms may be counted as commercial and vice versa. DNRC suggests the commercial sector be defined by SIC code, as shown in Table 4.

Table 4
DNRC Commercial Sector Classification

Codes	Description
40-49	Communication, electricity, gas and sanitary service
50,51	Wholesale trade
52-59	Retail trade
60-67	Finance, insurance, real estate
70-89	Services
91-96	Public administration

Using this approach, of 32,255 commercial accounts served by Montana Power in 1982, only 83 percent could be defined as commercial sector. Included in the remaining 17 percent were such accounts as mining, pipelines, agriculture, manufacture, and transportation.

Assuming that other utilities have the same proportion of industrial customers classified as commercial accounts as does MPC, we can estimate a statewide total number of commercial customer accounts at less than 40,000. However, this number is considerably in excess of the number of commercial establishments shown in the U.S. Department of Commerce (1982), "County Business Patterns."

Table 5
State Commercial Establishments by SIC Code

SIC	Type	No. of Establishments
50,51	Wholesale trade	1,797
52-59	Retail	5,702
60	Banks	175
61,62,67	Credit, investment	329
63,64	Insurance	527
65,66	Real estate	724
70	Lodging	457
72	Personal services	560
73	Business services	469
75	Auto repair and service	400
76	Miscellaneous repair service	197
78	Motion pictures	89
77	Amusements	212
80	Health services	1,213
81	Legal services	388
82	Educational services	55
83	Social services	300
84	Museums/art, etc.	8
86	Membership organ./Churches	671
89	Miscellaneous	436
40-49	Transportation	1,006
07-09	Agricultural services	211
90-99	Nonclassifiable	1,258
	TOTAL	17,184

Source: U.S. Department of Commerce, 1982. "County Business Patterns - Montana," Washington, D.C.

Part of this difference is explained by the decision of the Department of Commerce not to include education or government establishments as commercial businesses. These make up roughly 20 percent of Montana Power accounts that DNRC classifies as commercial; however, applying this proportion statewide would only raise the total to about 21,000. The difference between the estimated 40,000 accounts and 21,000 establishments must be due to some establishments having more than one account and some accounts being for uses such as phone booths and billboards.

MPC Commercial Sector

Figure 2 depicts the cumulative frequency distribution of MPC commercial sector accounts in terms of MWh sales in the twelve months of October 1981 through September 1982. Fifty percent of the accounts have an annual consumption of less than 7,000 kWh. Figure 3 presents the distribution of the cumulative consumption of Montana Power commercial sector accounts. This estimate shows that electricity consumption is very concentrated in the sector -- 50 percent of total consumption is contained in the top one percent of accounts, and 90 percent is included in the top 25 percent.

Figure 2

CUMULATIVE FREQUENCY DISTRIBUTION
MONTANA POWER COMPANY COMMERCIAL ACCOUNTS

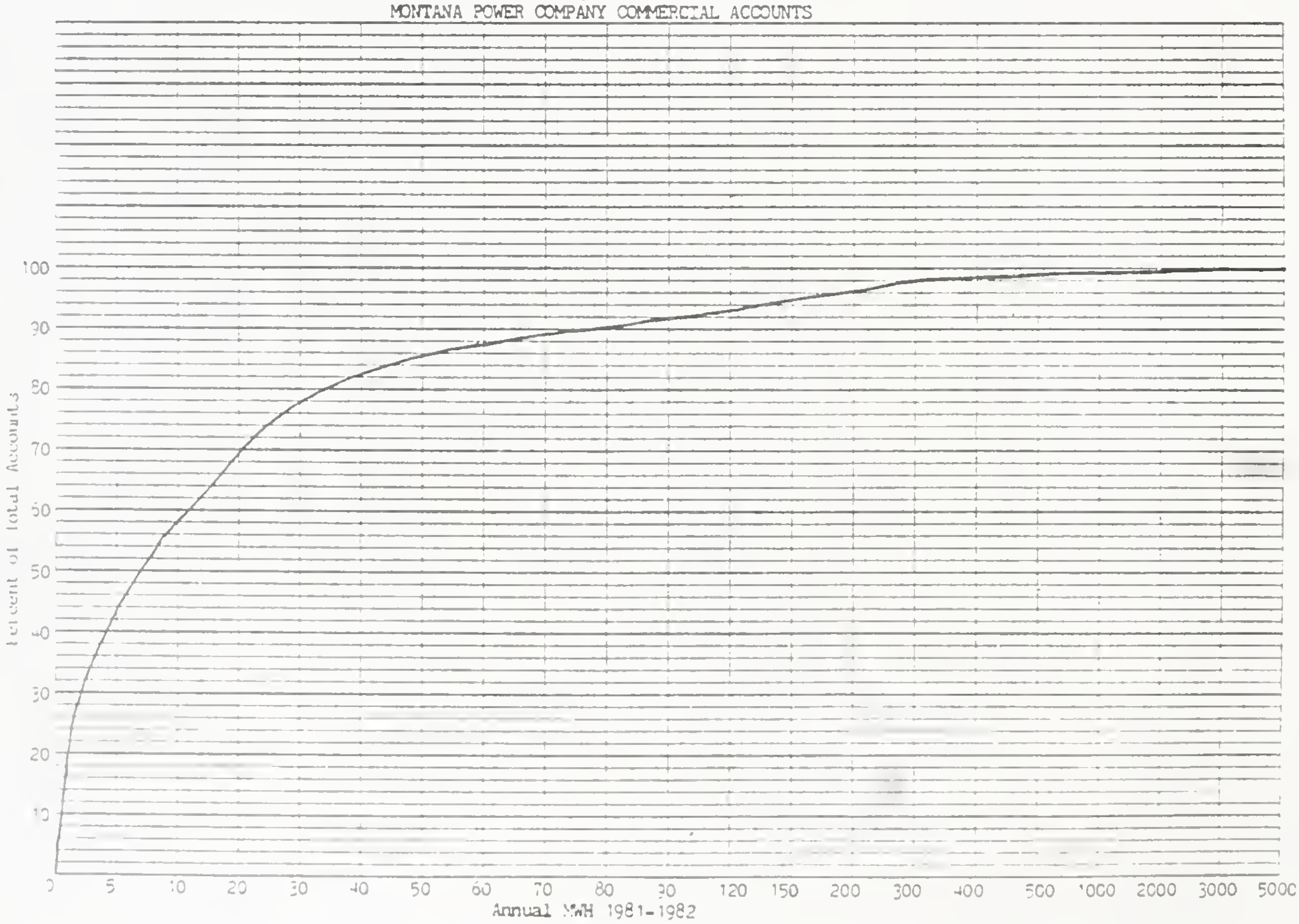
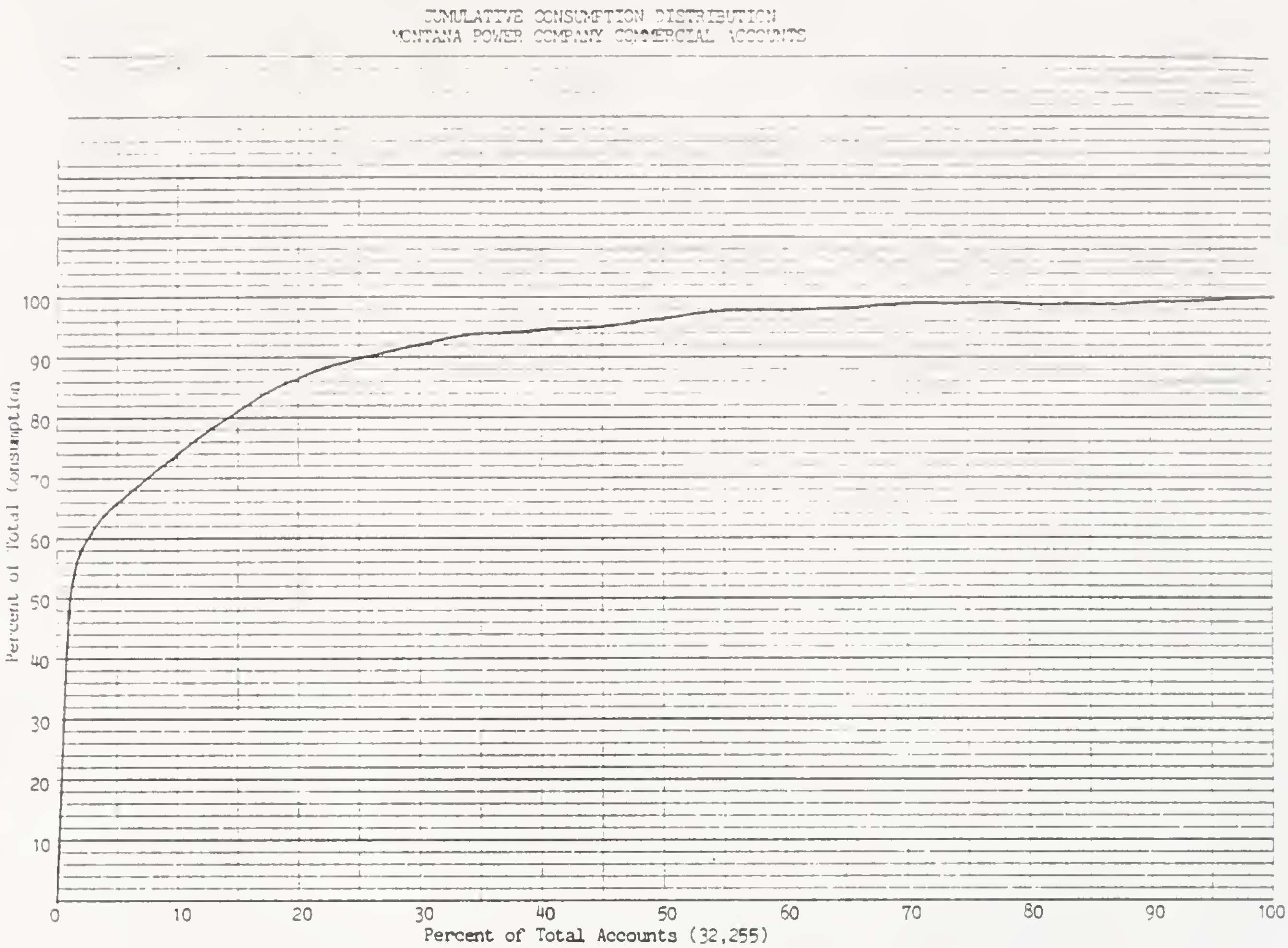


Figure 3



There is significant difference between the MPC commercial classification and that of DNRC. Fifty-eight percent of MPC's 32,255 commercial accounts, with 65 percent of 2,029,590 MWh of commercial sales, would be defined as commercial by DNRC. Seventeen percent of the accounts, with 25 percent of the sales, were not in the commercial sector according to DNRC. The remaining 25 percent of the accounts, and 10 percent of sales, were by accounts not assigned an SIC code. (The SIC codes were assigned for rate purposes by MPC district offices. MPC has noted that their use for conservation analysis could be

questionable.) The twelve DNRC commercial categories accounting for the greatest consumption in 1982 are listed in Table 6.

Table 6
Annual Consumption of Montana Power Commercial Customers in 1981-1982

SIC	Type	No.	Total MWh	Mean (MWh)	Std. Dev.
54	Food Stores	539	159,801	296	546
82	Educational	697	155,716	223	1300
65	Real Estate Operators	2,503	107,055	43	203
80	Hospitals/Public Care	611	93,839	154	674
70	Hotel/Motel	778	91,290	117	505
58	Eat/Drink Places	1,171	91,286	78	89
49	Utilities	594	65,618	110	765
91	Government	823	52,681	64	254
48	Communications	463	40,033	86	317
55	Auto Dealers/Service	1,015	34,848	34	63
53	Retail	167	34,102	204	379
60	Banking	183	30,324	166	336
		9,544	956,593		

Energy Consumption in Institutional and Government Buildings

DNRC has studied energy use in some categories of buildings around the state. Using data from the state's Institutional Building Grants Program (IBGP), DNRC estimated energy use in buildings from the following types of commercial accounts:

1) Government

2) College and Universities

3) Hospitals

4) Public Care

5) Elementary Schools

6) Secondary Schools

Samples of fifty of each building type were drawn from the IBGP data base. Estimated characteristics included average square footage, electricity, gas and total energy use per square foot and standard deviation of each. Energy use estimates are normalized by the building areas. Very good numerical agreement was shown between the total energy consumption per square foot by building type in Montana and of that estimated Hirst and Eastes (1980) in their study of Minnesota institutional buildings.

Table 7
Energy Use in Institutional Buildings

	Type	Ft^2	Elec. Btu/ft^2	Gas Btu/ft^2	Total Btu/ft^2
Elementary Schools	Mean	20,915	17,856	123,786	148,366
	Std. Dev.	21,690	16,559	46,787	51,382
Secondary Schools	Mean	54,926	16,635	109,915	126,540
	Std. Dev.	51,116	11,308	50,266	50,904
Colleges	Mean	32,426	23,354	151,650	174,874
	Std. Dev.	29,650	8,645	69,249	73,166
Hospitals	Mean	76,248	67,526	303,947	371,472
	Std. Dev.	68,412	53,527	172,429	112,378
Public Care	Mean	30,472	42,235	233,119	275,354
	Std. Dev.	38,116	51,483	150,518	101,004
Government	Mean	30,822	27,031	162,453	190,444
	Std. Dev.	33,586	24,547	115,509	122,515

Source: DNRC, 1982. "Institutional Building Grants Program-Building Energy Consumption Reporting System," Helena, Montana.

Hospitals tend to have the largest buildings as well as the greatest consumption per square foot, followed by public care facilities. Secondary schools have the lowest energy consumption rates. Part of these differences are explained by different time

dependent utilization rates and in the case of public care and hospitals, by greater ventilation requirements.

Estimating Floorspace and Numbers of Institutional and Government Buildings

As part of a BPA-sponsored program, DNRC estimated annual electricity consumption of institutional buildings in BPA's service area in Montana, approximately the western third of the state. Synergic Resources, Inc. (1982) has developed a series of regression equations for the Pacific Northwest that predict institutional building floorspace based on population, employees, students and so forth. DNRC applied these to the BPA service area, along with above estimates of electricity area-dependent consumption, to estimate annual electrical energy demand. There are no prior estimates of floorspace for local government buildings in the area. Therefore, regression equations were developed to enable predictions of floorspace based on population or number of local government employees. A sample of local government floorspace in twenty Montana towns was used to fit the equations. The best fit was observed using employees as the dependent variable, although the predictive ability of the population based specification also was good. Figures 4 and 5 illustrate the regression lines produced by the two methods. The slopes of the lines are quite similar.

Figure 4

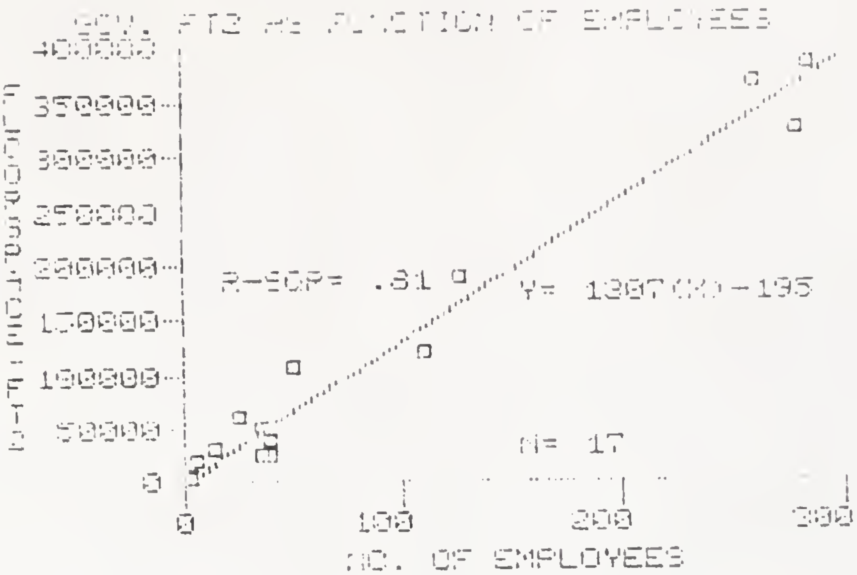
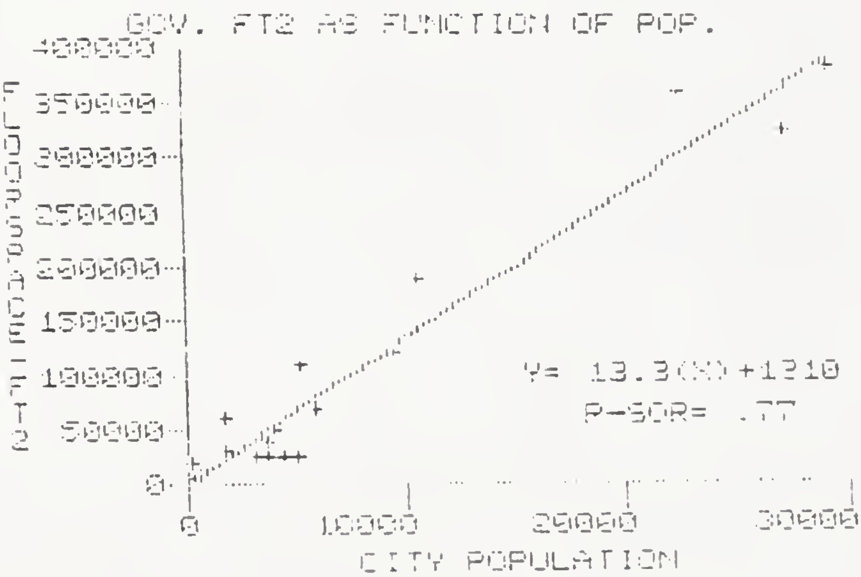


Figure 5



This aggregate information was used to create an initial estimate of institutional building electrical energy use in western Montana. This area is more temperate in climate and is also older and more densely populated than the state as a whole. Table 8 displays the BPA service area consumption estimate. (Regression functions used to create this data series are found in SRC (1982) "Base Floorspace Estimates for Major Building Types.") Unfortunately, these estimates cannot readily be compared with published consumption data from the utilities.

Table 8
BPA Service Area Institutional Building
Electricity Consumption Estimate

	Ft^2	Number of Buildings	Electrical (Btu/ft^2)	Annual MWh
Loc. Gov.	1.6×10^6	55	27,000	12,670
Schools	7.4×10^6	195	17,200	14,660
Colleges/Univ	4.3×10^6	310	23,300	29,430
Hospitals	1.3×10^6	25	67,500	25,730
Public Care	0.6×10^6	20	42,200	7,420
State	1.6×10^6	220	23,000	10,790
TOTAL	16.9×10^6	825		100,700

Sources:

SRC, 1982. "Base Year Floorspace Estimates for Major Building Types," Bonneville Power Administration, Portland, Oregon.

Montana League of Cities & Towns, 1980. "A Survey of Cities and Towns within Montana," Helena, Montana.

State of Montana, 1982. "Building Energy Consumption Reporting System," Helena, Montana.

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II. PROPOSED METHODOLOGY

A Study Approach for DNRC

DNRC has considered several approaches to studying the state commercial sector. Commercial sector analysis models are of three basic types: end-use engineering models like the Oak Ridge Commercial Energy Demand Model, econometric models such as the PNUCC commercial sector model, and engineering heat flow models, preferably based on survey information, such as DOE-2. DNRC has identified the latter approach as the most promising for its purposes.

The Oak Ridge CEDM model is probably the best forecasting model available for the commercial sector, especially for macro-economic prediction. However, the lack of explicit detail for analyzing conservation options would limit its usefulness for DNRC. Synergic Resources is revising the floorspace projection component that would make the model more suitable for use in Montana, where historic floorspace estimates are deficient. It is not known whether there might be time or monies for application of the CEDM to Montana as part of this study.

Econometric models likewise typically lack the detail necessary to analyze specific conservation methods. While valuable for load analysis and forecasting, they do not appear to present the most suitable mode of study.

Building heat flow models predict building thermodynamic performance given various assumptions about building construction characteristics and climatic influences. This heat-loss approach is more suited to specific micro-analysis of conservation options than the previous methods. One exacting requirement is that a prototypical building be developed upon which to simulate different conservation measures. For the residential sector this is a fairly straightforward matter. One, two, or at most three prototypes are determined from existing information or survey data. However, for the commercial sector, building types are exceedingly diverse. In order to use such an approach, DNRC [illegible] that as many as ten building types will have to be used.

The analytic structure of heat-loss simulations involves area specific calculations of thermodynamic flows from structures to the environment based on the difference between interior and exterior ambient temperatures and the R-value of the material in question. The equation is intrinsically additive, computing losses for each particular functional building segment and then summing the results. This includes losses through walls, ceilings, ground slab, windows, and doors. Additional subroutines calculate internally generated heat based on gross floor space and air infiltration based on numbers and sizes of windows and doors. Glazed areas require more involved calculation because of radiant gains which vary depending on solar geometry. Different algorithms are specified depending on

the climatic conditions, that is, whether the building is in heating or cooling mode. A great complication in these models is the thermal interaction of the building shell, interior structure and internal heat gains on the performance of HVAC systems.

Another possible drawback of the thermodynamic models is that they may not address some of the conservation potential associated with electrical equipment operation and replacement, since they concentrate on thermal flows.

Data Collection

The greatest barrier to an accurate assessment of the energy conservation potential is the lack of substantiated information on energy use characteristics of existing capital stock. Says Eric Hirst (1980):

> "Improved efficiency of energy use offers the potential to reduce growth of energy use, save money, reduce the adverse environmental effects of energy production, and provide additional time to develop alternative energy sources....The information currently available to address these issues is inadequate. Data are needed to deal with three types of issues: a) current status of energy use in buildings, plus details on energy using capital (buildings, appliances, equipment); b) changes over the time in energy use and capital stocks; and c) determinants of changes (information on fuel prices, GNP, government conservation programs, availability of fuels, utility promotional or conservation activities). . . . "

Data sources are extremely deficient for the Montana commercial sector. Such lack of data often results in sophisticated models of the types described being run with flawed numerical inputs. Hirst and Eastes (1980) have shown that such input errors make the analytic conclusions nearly worthless.

Consequently, a careful data gathering effort on the commercial sector in Montana is of paramount importance. DNRC proposes a two-tiered approach. First, a large initial broad-based survey will attempt to elicit concise but descriptive information from a sample drawn from Montana Power's accounts list. Second, DNRC will conduct engineering studies of representative buildings to gather detailed information on commercial building characteristics.

The survey will be accomplished through a mail-out instrument (described below) with telephone follow-up. An analysis of the survey should provide DNRC with an understanding of typical characteristics of buildings in the sector. Based on a review of previous studies, we assume it will be possible to break the sector into building categories and to identify a real structure to serve as a "prototypical building" for each category. A suggested breakout of building types by SIC code is shown in Table 9. While DNRC is not certain that this classification is descriptive of the large number of building types in Montana, the classification does reasonably depict the major commercial sector

activities. Another difficulty in this approach is that the survey will be based on account listings whereas the units of energy consumption in the sector are buildings. DNRC has not determined the statistical problems this may present.

TABLE 9

Building Types

Type	SIC Code
1) Offices	60-67, 81, 83, 86, 89
2) Small Retail	52-59
3) Large Retail	55-59, 72, 76
4) Warehouses	422, 50, 51
5) Restaurants	58
6) Food Stores	54
7) Lodging	70
8) Hospitals/Public Care	806
9) Schools	821-829
10) Public Administration	91

Given the relatively small number of commercial establishments statewide, a valid sample of each sub-sector (ex. hospitals, restaurants, offices, etc.) will require a good portion of these to be surveyed. Stratified random sampling techniques will be preferred with subclasses for geographic

representation; however, the sample will not be stratified by climate. Given ten sub-sectors, DNRC statistician Lynda Steele suggests that a sample size as large as 4,000 for a statewide study could be necessary to ensure reasonable confidence levels. Validation tests will be built into the survey to trap erroneous responses. Hirst and Eastes (1980) noted that this can greatly reduce the standard deviations in the findings.

An important aspect of this process will involve careful specification of necessary data. The following parameters are suggested content of the survey:

1) Major building activity (10 types)
2) Gross floorspace, heated area, cooled area
3) Energy use by fuel type
4) Age of structure
5) Utilization rate (operating hours)
6) Number of employees
7) Equipment configurations (type of HVAC, lighting, etc.)
8) Temperature settings-winter/summer
9) Roof/wall insulation
10) Glazing type and percent
11) Location

The second portion of the data gathering will involve engineering audits of the selected prototype buildings. DNRC

hopes to use statistical measures to identify specific buildings from the survey population as being typical of a building activity type. These audits will be extensive, gathering data on a variety of physical information on building geometry, insulation levels and equipment types. The resulting information will serve as input to the heat flow model chosen for later simulation of conservation options.

Given the budget under which this study will be conducted, DNRC hopes to use as much existing simulation and/or field data as possible in order to reduce expenses. The IBGP data base may be significant in this regard. Extensive engineering audits already exist for many of the buildings which make up three of the required building types (hospitals/public care, education, and public administration). Additionally, building types such as food stores and restaurants in Montana may not differ significantly from other regional prototypes, which could be substituted in their place. In this fashion, DNRC may be able to reduce the number of engineering audits required. One problem of the prototype approach is that building models are to be selected based on statistical measures of central tendency. As shown in Table 7, the standard deviations of energy consumption in commercial buildings are substantial. The audit of an actual structure which fits the survey means will not insure that the specific one chosen can be generalized to the population. DNRC must address this problem prior to beginning its analysis.

Analysis

Records of building energy consumption will be carefully analyzed along with climatic and micro-climatic influences on structural thermodynamic performance. These effects will be normalized through use of the degree-day data. This will allow analysis of specific conservation measures and policy alternatives. The accuracy of this approach in large part depends on careful data reduction and model calibration. Of course, analysis of the fiscal effectiveness of such measures will require cost-benefit and possibly other econometric methods. The exact model to be chosen for the simulations will have to be based on study of the specific ones available. DOE-2 or SUNCAT might serve DNRC's purposes. Other more simplified models such as BEEP or other modified "bin methods" will be considered. This could cut time and costs and allow extensive sensitivity runs. The question in this regard is whether accuracy in simulation would be significantly compromised.

The analysis will involve a number of computer runs on prototypical Montana commercial buildings derived from analysis of the broad based survey and audit data. These conservation options will be in turn compared against the marginal cost of electricity. Multiple regression equations will be created to attempt to discover the major explanatory variables for energy use in the various building types. This may lead to additional

simulation runs as measures are uncovered that may suggest greater conservation potential in the prototypes than those previously examined. Additional research will be considered into methods of predicting commercial building annual saving fractions as a function of area dependent investment or other factors similar to the methodologies used by Ross & Whalen (1982) and Hirst (1980). Finally, a supply function will be created that relates the amount of conservation potential in commercial buildings that exists at various levels of mills/kWh with various conservation alternative "packages." These results then will be generalized to the population based on the results of the initial survey.

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A SURVEY APPROACH FOR THE DNRC COMMERCIAL SECTOR STUDY

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Working Paper

Energy Division/Planning and Analysis Bureau
Department of Natural Resources and Conservation
April, 1983

Introduction

The objective of the DNRC commercial sector study is to estimate the electricity conservation potential for the commercial sector in Montana. The result will be an estimate of the amount of electricity that can be conserved at various levelized costs. The study is specifically interested in the conservation of electrical energy rather than peak capacity. The study will consist of engineering audits and computer analyses of the energy use and conservation potential of a sample of commercial buildings in the state. The Montana Power Company service area will serve as DNRC's initial case study; approximately 100 buildings will be studied.

Two problems will be addressed in this paper: the relative accuracy of alternative methods of investigation and the feasibility of each method. For DNRC's purposes, commercial buildings are those generally used by enterprises with SIC codes between 50 and 91; their distinguishing feature is their minimal use of energy for process purposes.

Auditing all commercial establishments in the state would be impractical and prohibitively expensive. Sampling will be used to characterize the universe of buildings.

Most commercial sector investigations in the past have used a limited number of building prototypes as inputs to computer simulations (Mazzucchi, 1982). The results from the study of these prototypes were then generalized to the population to estimate total conservation potential. Design of the prototypes or selection of a representative building were sometimes based on survey results but more commonly on professional judgment. Significant error in the estimates can occur in both the choice of a representative building and in relating the building back to the population. Because prototypes historically have relied on an individual's subjective judgment, it has been impossible to quantitatively assess the representativeness of the chosen building or the conclusions drawn to the population. Therefore, DNRC proposes to use a more statistically rigorous method to select buildings for analysis.

The following discussion examines various survey approaches, the accuracy requirements of the study and analytic considerations in the survey design. As a result of this inquiry, DNRC has decided to use a stratified utility sample in its survey strategy, with on-site audits. This is a statistically more valid method than the prototype approach (Yates, 1960), since it provides a quantitative measure of the representativeness of the objectively chosen sample and permits measurably accurate conclusions to be drawn to the population.

DNRC has ruled out the possibility of using mail surveys as the primary tool of the survey. This will not preclude their use as a supplemental tool, or as a part of a multi-stage survey design. Mail surveys have a cost advantage over most other techniques, although the quantity and accuracy of information obtained may be unsatifactory.

Mail surveys can be unreliable due to poor response rate, response quality and response patterns. The rate of return on previous commercial mail surveys (under 50%) has been disappointing (Baker, 1982). The responses from a commercial sector survey are likely to contain a large number of missing or

inaccurate answers due to the respondents' lack of knowledge. Returned mail questionnaires often follow a pattern over time and, particularly in the early stages of mail back or in studies with low response rates, the returns are unlikely to be a random subsample of the original mailing (Cochran, 1977). These shortcomings cast serious doubt on the conclusions that can be drawn from a mail survey of the commercial sector.

A consultant has made the rough estimate that the selection of individual buildings, on-site engineering audits of each, and later analysis could cost approximately $1,000 per building (McDonald, 1982). This estimate must be verified but seems plausible to DNRC. While this cost per building will limit the total sample size, DNRC believes that its proposed approach will result in greater accuracy than using a mail or phone instrument as the primary tool to gather information on building characteristics.

Either of two sampling frames could be employed in this type of study. Areal sampling uses geographic regions to group sampling units. A utility frame uses accounts. Both methods have unique advantages and disadvantages.

<u>Area Sampling Frames</u>

Areal sampling is a two-stage approach. Territory is used as a basis for selecting groups of buildings. Possible area classifications include counties, townships and zip codes. Specific areas are chosen by random, analytic, or purposive techniques. A sample is then drawn from the list of buildings in the selected area. Business licensing or county assessor's records are two such lists.

The main advantage of the areal technique is its convenience and relatively low cost. Accessing the building records and conducting the audits would entail a minimum of time and travel.

A disadvantage of the areal technique is that it often lacks the representativeness of a true random sample (Cochran, 1977). Although it is possible to use analytic schemes to purposively choose "representative areas" from the population, it is difficult to know what sample bias such a method will introduce. Another difficulty is choosing the appropriate demographic estimator on which to base the selection. Finally, a purely random choice of areas could result in the selection of areas that are widely separated, thus negating some of the inherent cost advantage.

Other problems include incompleteness of the commercial building records. Institutional and religious buildings are not listed in county assessor's records or business licenses. This presents difficulty in creating an adequate building selection list. Estimates of conservation potential in the buildings must be related back to the population, which usually requires establishing a relationship between a known demographic variable in the sample and one in similarly organized census data. Commonly, this relationship is based upon correlations between employment and commercial floorspace. It may be possible to predict this based on data gathered in the sample and from statewide census information although any large variance would detract from the overall confidence level of the final conservation estimate.

Energy consumption records must be obtained for each selected building. This requires obtaining the building owner's permission to release the utility records. Sample replacement would probably be necessary in cases of non-cooperation by building owners and is discussed in detail in Appendix 4.

Utility Account Sample Frames

The list of utility customer accounts can be used to describe the universe of buildings to be sampled. Several types of sampling methods have been considered. A simple random sampling approach involves chance selection of commercial accounts over the service area. The major drawback is that, in a small sample, important portions of the distribution may be missed. An unequal probability of selection technique could heavily sample the largest consumers where theoretically the largest conservation potential exists and lightly sample the rest of the population. However, such a sample might not adequately depict the total distribution. Smaller individual accounts, such as educational buildings, could be excluded from study although their aggregate consumption is quite large. The weighting of samples necessary in this type of survey creates considerable computational difficulty.

Cluster sampling would involve an approach similar to the areal techniques, choosing subdivisions of accounts rather than subdivisions of a geographic area. Clusters could be based on counties, zip codes, or metering routes. The problems involved in choice of the clusters would be analogous to those involved in choosing areas from an areal sampling frame. Definition of the areas would also be subject to limitations of locational information contained within the utility account codes. Accuracy and bias problems involved seem to outweigh potential cost advantages. Experience has shown that cluster samples will produce standard errors that are about one and one-half times as large as those obtained in simple random sampling (Warwick and Lininger, 1975). Thus, one would trade a larger sample size (and its associated costs) for reduced travel costs in order to achieve the same degree of accuracy in a cluster sampling design as one would get with a simple random sampling design.

DNRC's preferred technique is to sample the utility accounts stratified by their electrical energy consumption so that all strata are represented. This corrects for the possibility that a survey based solely on consumption will miss a portion of the distribution. Since commercial floorspace is strongly correlated with population, most of the selected accounts would occur within a few populous areas within the state (Parker, 1982). However, some of the selected structures would be in outlying areas because of the stratification used in sample choice. In any case, by using the utility accounts as a sample frame, sampled buildings would automatically be associated with their utility consumption records.

Problems with Utility Account Sampling

A utility account frame is not a perfect description of the universe of commercial buildings. Some buildings, such as vacant buildings, those ready for demolition, newly constructed ones without electrical hookups, and commercial accounts that are classified as residential, may be excluded from the sample. The exclusion of most of these types is generally advantageous since they would

otherwise require replacement in an actual sample. Omitted commercial accounts classified as residential are of some concern, although in the Westat survey (1982) such types comprised less than two percent of non-residential buildings. Results from a residential survey by TVA indicated the magnitude of this error in survey estimations to be quite small (Westat, 1982).

Other, more difficult problems result from the use of utility accounts to represent buildings. In some cases this is accurate; however, an account may represent several buildings such as several grocery stores in a chain. Conversely, in mixed use buildings such as shopping malls, several accounts may exist. Also, a single establishment may maintain several accounts for accounting or tax purposes. The Westat study found 16 percent of all units in the sample classified as mixed use. There was no estimate of what fraction of the accounts contained multiple buildings. Both of these discrepancies introduce bias into the sampling procedure. Mixed use buildings where each business has its own utility account are apt to be chosen in the sample more often, relative to the actual number of mixed use buildings in the population. Buildings in groups that are represented by a single accounts have a smaller chance of being selected. Both of these problems can be addressed after the sample is taken through post stratification. The Westat survey found a much better match of accounts to buildings was obtained when accounts were matched to meter service addresses. This reduced the number of effective accounts in the Portland Electric file by 20%, and the number of effective accounts in the Seattle City Light file by over 40%. Because of the size of the files, both accounts and service addresses must be computerized in order to match the records. Montana Power has indicated that computerized "matching" of accounts to meter service addresses should be possible on their commercial account data (Leland, 1983). In the event that matching to service addresses is not feasible, it will still be possible to use the account sampling frame. Post-survey data for mixed-use and multiple building accounts would be manipulated after the survey and multiple building accounts would be sub-sampled.

Of the utility accounts in the Westat study, ten percent required replacement. Roughly half of these were private residences, apartment houses and farm structures. The other half were non-buildings such as street lights, trailer parks, billboards and other such miscellaneous accounts. Some of the chosen accounts had incomplete billing records because of seasonal inactivity, vacancy, or reading errors. All of these were replaced. Accounts representing multiple buildings required subsampling to choose structures. About 12% of the accounts refused to release their energy consumption records and thus also required replacement. Although the survey bias introduced by replacement is difficult to quantify, it is preferable to inclusion of insufficient or flawed data. (Replacement is discussed in detail in Appendix 4.)

Survey and Audit Data Management

Experience of past investigators has shown that survey and audit data often contain many errors that significantly reduce the quality of the observations (Hirst, et al., 1981). Three types of error detection tests are recommended: statistical tests for outliers, engineering validation, and internal consistency checks.

Statistical tests can be developed to identify outliers that may represent flawed data. In the Oak Ridge study, this was accomplished by computing measures of central tendency for the distribution, deleting the top and bottom 10% percent of the points and computing a trimmed mean and mean absolute deviation. From these measures, confidence limits were constructed. Values not contained within the interval were rejected. Based on study results, the mean is often only slightly affected, but variance, which is of concern in the DNRC study, was greatly reduced.

Such tests might find application in detecting and correcting inaccurate audit information and in final (sensitivity) analysis. However, DNRC would not eliminate data values solely on the basis of their being outliers.

Engineering validation is based on detection of input values that are outside of a reasonable range of expectation. This applies to time of construction, fuel consumption, floor area, and so forth. In this fashion, vacant buildings, non-buildings, data input errors and audit errors are detected for correction or replacement in the sample.

Internal consistency checks are more obvious. For example, the portion of the building that is conditioned may not be less than zero or greater than gross floor space. A building's consumption records must show consumption of the fuel listed as its primary heating source, and so forth.

These tests can be computerized. Such a system of error and outlier detection should help to insure quality in the data base, thus possibily reducing the variance and thereby narrowing the width of the confidence intervals around the final estimates.

Sample Size

The final product of the study will be an estimate of megawatt-hours of commercial sector conservation potential that exists at varying levelized costs. Given inaccuracies at the survey, audit and analysis levels, a considerable margin of error is expected. Even the most complex commercial building simulations are only accurate to within 10% of actual energy consumption (Wall and Rosenfeld, 1983). With the limited funds available for the survey, it is important to identify an approach which will allow the greatest possible accuracy in the final estimate at the lowest cost. In general, an 80% confidence level is taken by consensus of statisticians to be a minimum acceptable level (Cochran, 1977).

The estimate of conservation potential will require building energy audits by trained persons to guarantee accurate data. The necessity and cost of retaining such professionals to do the building audits has set an outside limit on the sample size. DNRC has received a rough estimate of $1,000 per building survey and audit. Since the budget for the project is about $100,000, the number of buildings to be audited is predetermined to be 90-100, based on costs. This is, unfortunately, a small number given the known variability in the population. The sample survey design must make the best possible use of all available information, since there will be no leeway in the sample size.

Confidence intervals around estimates are usually stated in terms of the point estimate plus or minus some number of standard deviations of the point estimate. In order to decrease the size of the confidence interval width, the standard deviation must be reduced. For example, the estimated standard deviation of the sample mean $\bar{X}$ is $s_{\bar{x}} = \sqrt{\frac{N-n}{N}\frac{s^2}{n}} = s\sqrt{\frac{N-n}{N}}\sqrt{\frac{1}{n}}$

where s represents the standard deviation of the original observations.

The three components of $s_{\bar{x}}$ are (1) the factor (N-n)/N which indicates the influence of the relative or proportionate sample size, (2) the factor 1/n which represents the influence of the absolute sample size, and (3) the square root of the sample variance, s^2. Mathematically, the absolute sample size n is of much greater importance than the relative sample size n/N.

Since n and thus 1/n are already determined by cost, and since the relative size of the sample is of little importance mathematically, DNRC must concentrate its efforts on reducing the variance in the original observations and, therefore, the half-width of the confidence intervals (Warwick and Lininger, 1975).

The sampling design must take into account the treatment of multi-use buildings and accounts representing more than one building, so that information gained from <u>all</u> building audits can be used in the analysis. With a sample of size 90 or 100 where there is a known large variation, DNRC cannot afford any reduction of the effective sample size.

<u>Preliminary Variance Estimation</u>

In order to estimate the confidence levels that might be possible in the survey, preliminary values for the sample variance are necessary. The estimator for calculating the variance will be the annual consumption of electricity in commercial buildings. Usually variance is unknown before the actual survey and a pilot survey or limited data set is required. Since DNRC is limited to the use of a small sample, the initial estimate of the variance is important.

Consumption information on all commercial and industrial accounts is available from the Montana Power Company. DNRC defined commercial accounts as those with SIC codes other than 1-42, 44-46, 88, and 97-99. Of the 32,255 accounts on the Montana Power commercial/small industrial file, 24,172 had SIC codes. Of these, 75% (18,144) were classified by DNRC as commercial accounts. Table 1 summarizes the findings.

Table 1
Annual Electricity Consumption in MPC Commercial Accounts
(MWh)

N =	18,144
Mean =	70.44
Variance =	50,557.52
Standard Deviation=	224.85

The average MPC commercial account uses seventy megawatt-hours of electricity per year.

Using the MPC variance figure, it is possible to construct a preliminary estimate of the confidence levels possible when using a small sample and a utility sampling frame. The following equation determines the approximate sample size necessary given the accuracy and confidence levels specified (Williams, 1978):

$$n = \left(\frac{z_{\alpha/2}}{d}\right)^2 \sigma^2$$

where n = sample size

$z_{\alpha/2}$ = normal quantile which cuts off $\alpha/2$ of the area of the normal distribution in the upper tail

d = desired accuracy of the sample mean

σ^2 = variance of the population

α = risk

An iterative process may be used when "n" is given to determine acceptable levels of "d" and "$z_{\alpha/2}$."

In ONRC's case, funds exist to sample approximately 100 buildings. The mean consumption of the test sample is 70.4 megawatt-hours. This is taken to represent typical commercial building energy use. A minimum acceptable confidence level is taken as 80% corresponding to a z-score of 1.28 The error tolerance ("d") is varied so that a sample size of approximately 100 is indicated. With this small sample, an accuracy of plus or minus 29 MWh for the calculated mean must be accepted.

$$n = \frac{1.28^2 * 50{,}557.5}{29^2}$$

n = 98 buildings

Sample size estimation depends on the accuracy requirement (d) and the confidence level $1 - \alpha$. For instance, a more conventional confidence level of 90% and an estimate with an accuracy of plus or minus 10 MWh would result in a sample size of 829 buildings.

DNRC has considered the possibility of reducing the population by excluding some institutional building types from the survey such as hospitals, schools, universities and local government buildings. DNRC maintains a file of 722 buildings in the Institutional Building Grants Program. These buildings represent over 34 million square feet of commercial floorspace and 12,000 MWh of annual electricity consumption. Data can be drawn from buildings which have good Preliminary Energy Audits (PEA). (A copy of a PEA data sheet is attached as Appendix 5.) In lieu of sampling and an engineering audit, this information could then be used for input into the simulation model. The aggregate building data could be used to generalize the results to the population of institutional buildings. Until the data requirements of the simulation model are specified, it is not known whether the PEA audit information will be sufficient. Omitting these institutions will insure maximum sampling of unknown building types in the survey. Unfortunately, the PEA data is not quantitatively detailed. Further,

based on results by Hirst and Eastes (1980), about 30% of the PEA's probably contain inaccurate or missing data that would exclude their use in the analysis. Unless a series of default assumptions can be used within the simulation model, it may not be possible to exclude these buildings.

Even without removing the institutional buildings from the survey population, the variance of the actual sample data can be expected to be significantly less than shown above. Accounts sometimes represent several buildings; other times there are several accounts per building all of which increase the resulting variance. This will be isolated in the actual survey. Excluding accounts with very low consumption (e.g., less than 2,000 or 3,000 kWh/year; see Appendix 1) will tend to reduce the variance. Finally, non-buildings, vacant buildings and non-commercial buildings that tend to increase variance will be eliminated from the sample. Consequently, an 80% confidence level and a greater determination of accuracy as measured by confidence interval widths will be possible. ONRC will also try to control nonsampling errors which result from nonresponse, coding mistakes, etc. so that, to the extent possible, these errors will not affect the accuracy of the final estimates.

A Stratification Variable

Stratified sampling may result in greater precision in the survey results when compared to a simple random sample of the same size if the variable on which the population is stratified is highly correlated with the survey estimate, in this case, the electricity conservation potential in commercial buildings. Only a limited number of stratification variables are available when the sampling frame is the list of utility accounts. Theoretically, utility accounts could be stratified according to consumption or SIC codes.

In a 1982 study of commercial building retrofits, Ross and Whalen found little correlation between building type and resulting conservation. Since building type is somewhat correlated with building use, this tends to discredit an SIC code based stratification. Fortunately, the same study found a positive general trend between initial building energy consumption and resulting conserved energy after retrofit. Large consumers tended to have a greater conservation potential although no linear pattern was evident. Figure 1 shows the results of this study of 233 retrofitted commercial buildings.

Based on this evidence, ONRC will stratify on account consumption. Since the sample will be quite small, the study will be limited to three to five strata.

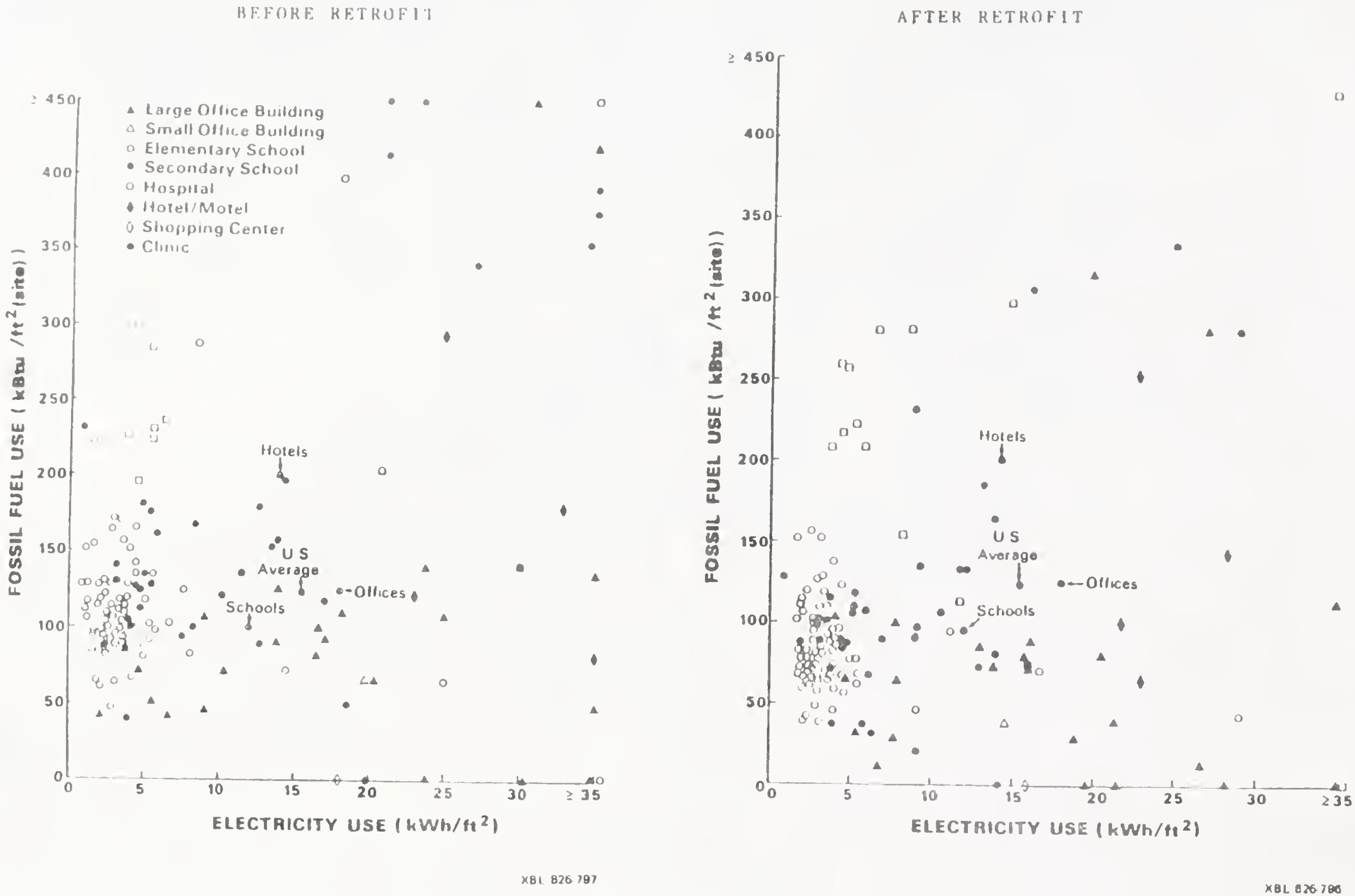

Fig. IA, B. Energy Use Before and After Retrofit--Note that the largest energy users (located in the upper right of each figure) tend to have the greatest reduction in energy use. Also, the figures show the national average energy use for various building types (denoted as ⊗). Our sample shows that electrical energy use of schools is much below the published school national average (ORNL, 1980); the overall source energy difference is about 50%.

Survey Design

DNRC will use the Montana Power Company's "commercial" account billing records as the sampling base for this study. However, because DNRC's definition of "commercial" customer is based on the customer's type of activity whereas MPC's definition of "commercial" customer is based on the volume of electricity used, DNRC will "narrow" the MPC "commercial" account file as much as possible to meet the current study's needs.

The extent of the sample frame will determine the scope of the conclusions drawn from the sample. The sampled population to which the conclusions are drawn will be MPC customers whose major activities have been determined by DNRC to be "commercial" in nature and whose annual electricity consumption falls between certain limits.

Therefore, DNRC suggests a multi-phase, multi-stage sample design for the survey of Montana Power's commercial sector. Phases A, B, and C attempt to narrow MPC's "commercial" account file to those accounts of interest which DNRC considers to be "commercial" accounts. These accounts will constitute the frame. Phase D describes the procedure for selecting a sample of buildings to be audited. Phase E describes the subsampling necessary if a master billing record is selected. Confidentiality of customer records will be maintained by funding MPC to contract with a mutually acceptable third party to conduct the study.

Phase A: Removing low consumption accounts

DNRC will choose an initial annual electricity consumption level below which it feels the conservation potential is limited, or of limited interest. This subsector will include nonbuilding activities such as billboards, phone booths, and possibly some commercial operations whose size and energy use patterns more closely parallel those of some residential customers. Any analysis of this subsector will probably be generic in nature. (See Appendix 1.)

DNRC will contact a sample of low annual consumption accounts to identify what these accounts are and what their major electricity uses are. Based on the description of the low consumption customers obtained from this brief survey, DNRC will determine a lower consumption boundary for its main survey. If the survey indicates that commercial concerns, as defined by DNRC, have annual consumption figures substantially higher than DNRC's initial cut-point, then DNRC will reset the cut-point at a higher consumption level and repeat phase A for the next group of customers.

The survey sample size and possible lower boundary starting points based on currently available information are discussed further in Appendices 1 and 2.

Phase B: Eliminating from consideration buildings whose conservation potential is known or can be determined from existing data

Because of the limited audit sample size, as many buildings as possible must be eliminated from the population; DNRC must concentrate its efforts where little or nothing is known about the conservation potential. Therefore, to the extent possible, DNRC will eliminate all groups of commercial customers on which

it has adequate conservation potential data. For example, DNRC's Institutional Buildings Grants and Loans Program might provide adequate information to determine the conservation potential of schools and hospitals, and these buildings could be removed from the population.

Conservation estimates for subsectors of the population eliminated under phases A and B can be added (with the appropriate caveats) to results from the main survey to obtain an overall picture of commercial sector conservation potential in the MPC service area.

Phase C: Removing the influence of the "small industrial" accounts

MPC's commercial/industrial account file includes an unknown number of accounts which DNRC considers "small industrial." DNRC believes that most of these occur among the higher annual consumption accounts, and that their affect on the variance will place almost the entire sample in the largest consumption strata under Neyman optimum allocation. (Optimum allocation calculations based on available data are shown in Appendix 2.) This being the case, DNRC must try to eliminate as many "small industrial" accounts as possible from the population.

DNRC will ask MPC to provide its commercial/industrial account file in two parts: one part will consist of the accounts in the commercial rate category and the other part will consist of the accounts in the industrial rate category. (MPC probably has between 2,000 and 7,000 industrial rate accounts. The lower count is the number for which SIC code information is currently available, and the upper count is the number of customers in MPC's industrial rate category as of September 1982.)

The industrial rate subfile will probably consist almost entirely of businesses which DNRC classifies as industrial; these accounts can then be removed from the population and used, if desired, for a separate study of that sector.

The commercial rate subfile will probably consist of the lower consumption accounts and will likely include some businesses which DNRC would classify as "industrial" rather than "commercial". DNRC will try to detect as many of the "industrial" accounts in this subfile as possible and remove them from the study population. This will be accomplished through scrutiny of the rate classification of commercial accounts to identify the small industrial accounts to be deleted, and scrutiny of the accounts in the subfiles as described below.

Paralleling Phase A, DNRC will survey each subfile separately by mail or phone to determine what the account is or does and what its major uses of electricity are. As in Phase A, the survey instrument will be extremely brief. The samples for these surveys should be about 400 accounts each, with the accounts selected systematically to provide an accurate picture of the full range of annual consumption.

DNRC will achieve two objectives with these surveys: (1) DNRC will determine the accuracy of the SIC codes as they appear on the subfiles, and (2) DNRC will locate the cut-points, if existant, in annual consumption that separate most commercial accounts from most small industrial accounts. Hopefully the entire industrial rate subfile will be small industrial accounts and its cut point will

be the lower end point. If certain small industrial SIC codes seem to be reasonably accurate, ONRC will eliminate them from the subfiles before sampling. Likewise, if commercial/small industrial consumption cut points exist, ONRC will truncate the higher consumption (industrial) accounts off the subfiles just as it truncated the lower consumption accounts in phase A. Thus, the sample frame will consist of the two rate-based subfiles, combined, less the lower annual consumption records removed in Phase A and those records removed in Phase B, and less the industrial SIC code records and/or higher annual consumption records removed from the subfiles as described here.

The worst case scenario would occur when the SIC code information appears to be too inaccurate or too spotty to be useful, and/or there appears to be no obvious breaking point between commercial and small industrial consumption, i.e, if small industrial and commercial seem to be extensively intermixed. In this case, the frame would consist of the two rate-based subfiles, combined, less the lower annual consumption records removed in Phase A and those removed in Phase B, and less the small industrial records detected during the examination of the subfiles. Obviously, this frame would be much larger than the frame mentioned above.

ONRC will have sampling problems with either frame because the frames are imperfect: each frame includes an unknown number of small industrial accounts which could be selected during the sampling phase. The worst case scenario frame will, of course, include more of these foreign elements. (Possible solutions to the problem of imperfect frames with foreign elements are discussed in Appendices 3 and 4.)

The extent and coverage of the frame will define the sampled population.

Careful record keeping will be necessary to insure the analysis accounts for the actual probability of selection and the type of sampling used.

<u>Phase D</u>: Selecting the accounts from the sample frame for auditing

ONRC will separate the accounts remaining in the (sampled) population after phases A, B, and C into three to five strata based on their annual electrical consumption. The overall sample size will be partitioned among the strata using optimal allocation if feasible (and proportional allocation otherwise). Within each strata, the commercial concerns of interest will be selected systematically.

Possible strata definitions and strata sample sizes, based on currently available data, including the small industrial accounts, are discussed in Appendix 2. These strata definitions and strata sample sizes, n_h, would be for the worst case scenario where few, if any, small industrial records could be removed from the rate-based subfiles.

Appendix 2 also shows the calculations for the sample frame if steps limiting the population resulted in approximately the 2,000 accounts with the greatest consumption being removed from the file.

Phase E: Relating Sampled Accounts to Buildings

Sampling units from phase D could be of 3 types: (1) a single commercial concern housed in its own building; (2) a single commercial concern which shares a multi-use building with one or more other (commercial) concerns, such as a shopping center where each unit's consumption is billed separately; or (3) a conglomerate commercial account representing several commercial establishments possibly located in various places around the state.

If the frame consisted only of type (1) sampling units, the sampling design and analysis would pose no problems.

Selection of a type (2) unit would mean that the building characteristics would have to be determined and the conservation potential of the building scaled down by some factor related to the establishment sampled, such as the floorspace. A portion of the building-related conservation potential would be added to the establishment-specific conservation potential to obtain the overall conservation potential for the sampling unit. Except for the problems associated with auditing the entire building in terms of its building-specific characteristics, there would be few problems specific to this kind of sampling unit since each of these units would be drawn with the same probability as the type (1) units. If, by coincidence, several units were drawn from the same multi-use building, some cost savings would be realized since only one building-specific audit would be performed.

If type (3) master billing records are drawn frequently, and if the average number of businesses included in each is relatively large, the problem should be treated as a cluster sampling problem. If the clusters are small and rare, all the elements should be included in the sample, thus receiving the probabilities assigned to the master billing records. A second possibility is to select one establishment from the master billing record and weight it up with the number of establishments in the record. (Kish, 1965).

Analysis

The information taken from the audit of sampled buildings will serve as inputs to a simplified building energy simulation program. Such simulation codes for commercial building analysis are generally available, but they often are proprietary. Validation of the selected program against a reference program such as DOE-2 will be an important part of the preliminary analysis. DNRC is concerned with annual energy consumption, and annual conservation potential. Therefore, the data requirements for the type of program DNRC desires are not nearly as rigorous as those necessary for an hourly simulation program such as DOE-2. Most of the commercial accounts using natural gas as well as electricity are serviced by MPC. Thus, for a large part of the sample, information on consumption of other fuels can be obtained with minimal problems.

Summary

The DNRC commercial sector conservation analysis procedure will consist of the choice of a sampling frame, the selection of buildings in the sample, the engineering audit of each building, and subsequent computer analysis to estimate

electricity conservation potential. This estimate will then be generalized back to the total MPC commercial sector population to determine the utility conservation potential. The estimate will be in terms of megawatt-hours at various levelized costs of electricity.

Given the funds available for the project, only about 100 buildings can be surveyed. A preliminary estimate of the variance in commercial building electricity consumption has shown it to be quite large. In order to insure reasonable accuracy in the final estimates, sampling errors as well as nonsampling errors must be minimized. Reducing errors can be accomplished by the following means:

1) The use of utility accounts matched to metered addresses to serve as a proxy for a commercial building sample frame.

2) A probability sample divided into optimally allocated strata representing the full range of commercial electricity users. (A preliminary mail or phone survey will be necessary to define the sampling frame.)

3) An interview/engineering audit procedure to reduce nonsampling error created by nonresponse and guessing.

4) A computerized data management procedure to provide engineering validation, internal consistency checks and outlier recognition in the audit data.

5) A short form mail or phone survey of accounts having very low electricity consumption and conservation potential.

6) A sampling replacement strategy to maintain maximum audit sample size which maintains the quality and representativeness in the data base.

7) Sub-sampling of accounts representing multiple buildings.

8) Analysis of post-stratified data.

This procedure is a major departure from the "prototype" buildings approach used to date. Underlying statistical theory indicates that a stratified sampling approach should give more measurably accurate results based on the previously described relationship between electricity consumption and conservation potential. This is particularly important in the DNRC study because cost constraints on the possible sample size require a rigorous efficacy in the survey results.

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APPENDIX 1
Low Annual Consumption Subsector

DNRC anticipates that the majority of the low annual consumption accounts will be non-building activities such as billboards and phone booths. DNRC's analysis of the conservation potential in this subsector will likely be generic in nature. For example, DNRC could recommend changing the kind of lighting on billboards and in phone booths, and then estimate the service area-wide conservation potential from the typical savings per phone booth or billboard and the number of phone booths and billboards in the service area.

It is, therefore, important to know the proportion of accounts in the sample that are billboards, phone booths, etc. since these proportions will be used to estimate the number of such units in MPC's service area.

DNRC suggests using simultaneous confidence intervals to determine, with some overall accuracy, the proportions of sampling units falling into each of several categories. A worst case sample of size 637 would provide 95% simultaneous confidence intervals for four major categories of sampling units with an allowable error of ± 5% for each proportion. A worst case sample of size 126 would provide 90% simultaneous confidence intervals with an allowable error of ± 10% each for four proportions of interest. (Tortora, 1978)

Only a limited amount of data would be collected by the survey of low annual consumption accounts. Type of account and categorization of end uses probably would be sufficient. A phone survey would be the preferred method. A phone survey would have two advantages: (1) the main survey lower consumption cut point could be determined more rapidly since there would be no delay from waiting for mail returns, and (2) the response rate would probably be significantly higher.

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APPENDIX 2
Creating Strata; Allocating the Sample

In order for stratification to be effective, it is necessary to stratify on the basis of a variable that is highly correlated with the variable of interest. Several studies have indicated that annual consumption is related to conservation potential, and ONRC chose to use this variable rather than the SIC code data, which MPC felt was tenuous information.

Several methods can be used to create the strata. One, the "eyeball" method, seemed inapplicable here due to the tremendous size and variation in the data (32,055 accounts ranging from 0 to 35,000,000 kWh annually); no strata breakout suggested itself. ONRC used the Dalenius-Hodges method, modified for data grouped in unequal size categories (Cochran, 1977), to determine possible strata boundaries based on data for the year ending in September, 1982. (The calculations will, of course, have to be redone on the actual population data.)

With the lower boundary of interest set at 3,000 kWh (in reality, the lower boundary would be determined in Phase A), ONRC determined the strata boundaries to be as follows for 3, 4, and 5 possible strata:

3 strata:	N_h
[3,000 - 15,000) kWh	9,600
[15,000 - 95,000) kWh	8,497
[95,000 - 35,000,000) kWh	2,944
	21,041

4 strata:	N_h
[3,000 - 10,000) kWh	7,005
[10,000 - 40,000) kWh	8,081
[40,000 - 140,000) kWh	3,922
[140,000 - 35,000,000) kWh	2,033
	21,041

5 strata:	N_h
[3,000 - 9,000) kWh	6,335
[9,000 - 20,000) kWh	5,028
[20,000 - 70,000) kWh	5,822
[70,000 - 200,000) kWh	2,472
[200,000 - 35,000,000) kWh	1,384
	21,041

NOTE: 11,214 accounts were under 3,000 kWh annually

Once the strata have been determined, the total number of building audits, presumed to be approximately 100, must be allocated among the strata.

If the sample of size 100 is allocated proportionally, then $n_h/N_h = n/N = 100/21{,}041 = 0.0048$.

This gives the following strata sample sizes:

3 strata:		4 strata:		5 strata:	
h	n_h	h	n_h	h	n_h
1	46	1	33	1	30
2	40	2	38	2	24
3	14	3	19	3	28
		4	10	4	12
				5	7
Total	100	Total	100	Total	101

Alternatively, using Neymen (optimal) allocation which minimizes the variance of the stratified sample's estimate of the mean per unit, the sample for three, four, or five strata is almost entirely allocated to the highest consumption strata as shown in the table below. This occurs because of the extremely high variances in the highest consumption strata, and points to the need for reducing tne variances in these strata to manageable levels.

Optimum Allocation

h	3 strata n_h	4 strata n_h	5 strata n_h
1	1	0	0
2	4	2	0
3	96	3	2
4		95	3
5			94
Total	101	100	99

Since the large consumption strata are likely influenced by the small industrial customers, these records need to be eliminated from the sampling frame prior to the sample selection wherever possible. Eliminating these records is discussed in phase C of the sampling plan.

As an example of the consequences of eliminating small industrial accounts, ONRC repeated the above calculations after setting the upper boundary at 150,000 kWh per year. (Hopefully this would approximate the commercial account upper cut-point.)

The strata populations become:

3 strata:	N_h
(3,000 - 10,000) kWh	7,005
(10,000 - 40,000) kWh	8,081
(40,000 - 150,000) kWh	4,072
	19,158

4 strata:	N_h
(3,000 - 9,000) kWh	6,335
(9,000 - 20,000) kWh	5,028
(20,000 - 60,000) kWh	5,313
(60,000 - 150,000) kWh	2,482
	19,158

5 strata:

	N_h
(3,000 - 7,000) kWh	4,776
(7,000 - 15,000) kWh	4,824
(15,000 - 35,000) kWh	4,795
(35,000 - 70,000) kWh	2,790
(70,000 - 150,000) kWh	1,973
	19,158

With proportional allocation, the sample sizes are:

h	3 strata n_h	4 strata n_h	5 strata n_h
1	37	33	25
2	42	26	25
3	21	28	25
4		13	14
5			10
Total	100	100	99

With Neyman (optimal) allocation, the sample sizes become:

h	3 strata n_h	4 strata n_h	5 strata n_h
1	7	7	5
2	33	10	9
3	60	39	23
4		43	24
5			39
Total	100	99	100

Arbitrarily removing the top 1,883 accounts for illustration has significantly reduced the variances and greatly altered the sample allocations as compared with the previous optimum allocations when the data included the small industrial accounts.

APPENDIX 3
Sampling from Imperfect Frames

A frame is perfect if every element appears on the list separately, once and only once, and if nothing else appears on the list. Every element must appear in the listing and in only one listing, and every listing must contain an element, and only one element.

The sampling frame is the keystone around which the sample selection process must be designed. Appraisal of the available or obtainable frames must dominate the search for good selection procedures.

DNRC believes that its phased approach to narrowing the account file will result in a better frame for its purposes than the original MPC account file; however, there will still be a fairly large number of problem records on the files. The number will probably be too large to ignore.

There are four possible contradictions to the basic requirement of a one-to-one correspondence between listing (frame unit) and element (sampling unit). Each interferes with the aim of selecting a single element with "epsem" (equal probability of selection method), when a single listing is selected with epsem. (Kish, 1965).

(A). Missing elements/noncoverage/incomplete frame: Elements inadvertently left off the MPC commercial file will probably consist mostly of small commercial operations which are billed at the residential rate; because of their size, the electricity consumption of these operations should resemble a residential building more than a commercial building and would, therefore, not be of too much concern to DNRC's commercial conservation potential study.

A potentially large category of elements missing from the frame would be those commercial enterprises which were part of an en masse elimination of industrial accounts under phase C of the sample plan. Very large commercial operations could conceivably be eliminated by the upper consumption cut point. Likewise, commercial concerns improperly labeled with SIC codes DNRC plans to remove from the file would go unnoticed. Nonetheless, DNRC believes that the risk of missing some commercial establishments is outweighted by the advantages of eliminating small industrial operations from the account file while creating the frame.

DNRC plans no action on this frame problem except to exercise great care in setting the upper consumption cutpoint and in eliminating SIC codes from the file when creating the frame.

(B) Clusters of elements appearing together, associated with single listings: This is a problem of unknown magnitude since DNRC has no idea how many master billing records appear on MPC's files, and will not know the size of the clusters or their extent until the Phase C mail or phone samples have been drawn.

If clusters occur frequently and the average cluster size is large, DNRC will treat such records with the standard cluster sampling approach. Clusters might occur as shopping center billing records or franchise master billing records, neither of which should be too numerous.

If the clusters are infrequent and small, all elements within the listing will be included in the sample.

Alternately, one element from the cluster can be selected at random and weighted up by the number of elements in the cluster.

(C) Blanks or foreign elements which occur in the frame when some listings contain no elements of the target population: In this case, foreign elements will be small industrial accounts which cannot be detected until the sample is drawn because they lack an SIC code and/or their consumption was below the upper cutpoint. Listings for vacant, nonoperational or demolished buildings would also be treated as blanks.

When selecting a sample of m member elements from a list of M members and B blanks (or foreign elements) by means of simple random sampling, one need only continue the random selection process until m usable member elements have been selected. With a sampling method other than simple random sampling, the rough advance estimates of M (the number of members) and M_h (the number of members in strata h) (obtained in this case from the "who are you" mail/phone surveys) are used to adjust the sample selection rates to account for the number of foreign elements that will be rejected after selection. Variances for aggregates and stratified means will be increased, but they must be tolerated.

The approximately m member units remaining in the sample after the foreign elements have been removed are analyzed as a subclass, selected with epsem from the entire list; actual subclass analysis depends on the type sampling used.

Kish strongly advises against substituting the next element on the list for a blank or foreign element since this procedure actually increases the probability of selecting any element in proportion to the number of blanks that precede it on the list. (Contrast this use of "substitution" to that in Appendix 4.) Selection bias generally results if the variable density of elements is correlated with the mean content of elements. In this case, the likelihood of foreign (small industrial) entries is probably greater at higher consumption levels; if consumption and conservation potential are positively correlated, we could get an erroneously high estimate of the conservation potential because the higher consumption units are more likely to be selected if the adjacent record is substituted for a selected foreign element.

(D) Duplicate listings where several listings represent the same element: It is possible that some commercial concerns might have several meters, but these should all go to a central billing account. In the case where meters are billed separately, the building or floorspace represented by such an account would be treated as if it were a selected unit in a (multi-use) building, paralleling the treatment of a selected store in a shopping center.

Out-and-out duplicate records should not be a problem since companies receiving duplicate bills would bring this to the attention of MPC.

REFERENCE

Kish, L. 1965 Survey Sampling, John Wiley and Sons, N.Y. (Summarized from p. 20 and p. 54 ff.)

APPENDIX 4
Replacement/Substitution for Missing Units

In nearly every sample survey, there will be some eligible units in the sample for which all or part of the survey data items are not obtained. DNRC is most likely to encounter this problem in the form of sampled establishments who refuse an audit. Whenever there is nonresponse in a survey, there will be bias in the survey estimates. There is no method of correcting nonresponse bias since the missing survey characteristics of the nonrespondents are, by definition, not available. The data collection phase of a survey must include extensive follow-up procedures to provide a high survey response rate (termed 85% or more by Chapman) and a low item nonresponse rate in order to hold the nonresponse bias to a minimum level.

In order to minimize the bias associated with the nonresponse remaining after completing the follow-up procedures, various authors have suggested a number of methods for adjusting or imputing values for survey nonresponse.

Perhaps the most common method of imputing for total nonresponse in a survey is to adjust (upward) the weights of the respondents in a way that accounts for the nonrespondents. The adjustments are made separately within sets of sample groups called "nonresponse weight adjustment classes." This procedure effectively imputes or substitutes the average values of the survey items of the respondents in each class for those of the nonrespondents in the same class. Weight adjustment classes are defined in such a way that respondents and nonrespondents in a given class have similar survey characteristics.

Another common procedure used to impute for total nonresponse is (field) substitution in which population units not originally selected into the sample are used to replace eligible sample units that do not participate in the survey. Ideally, potential substitutes should have survey characteristics similar to those of the nonrespondents.

There are two types of substitution procedures: (1) selection of a random substitute, and (2) selection of a specially designated substitute.

With a random substitution procedure, an additional population unit is selected on a probability basis to replace each nonrespondent. Usually the substitute is chosen from the same restricted population subgroup as the nonrespondent. More than one backup unit is selected for each sample unit prior to the actual data collection.

A procedure using specially designated substitute units identifies one or more purposively selected backup units to provide substitutes, if necessary, for each sample unit. The intent is to specify substitute units that have characteristics similar to those of the nonresponding sample unit.

Substitution should be used in combination with another imputation procedure to account for all the nonrespondents if there are some nonrespondents for which substitutes are not obtained.

Kish (1965, p. 558) has criticized substitution procedures indicating that substitution is of no help in reducing nonresponse bias since the nonresponses are replaced by responses that are presumably like the responses already in the sample. However, <u>all</u> methods used for nonresponse imputation suffer from the basic weakness that data for nonrespondents have to be supplied (imputed) from data provided by respondents. The key question in studying the worth of substitution procedures, according to Chapman, is whether or not the use of substitutes provides better proxy values for nonrespondents than those provided by alternative imputation procedures.

A specially designated substitution procedure often uses a substitute that is a geographic neighbor or an adjacent listing on the sampling frame. This proximity might result in better proxy values then those obtained from imputation procedures involving same type of "averaging" of the subclass characteristics. However, in cases where some information is available about the nonrespondents, better proxy values might be available from sample respondents than from substitutes because more information is available about the respondents than about potential substitutes.

Chapman believes that the type of survey for which the use of substitution is most appropriate is one that involves a deeply stratified, relatively small sample of population units. Surveys of institutions usually fall into this category. DNRC believes the commercial survey as planned fits into this category. In surveys of this type, the use of substitute institutions would tend to provide better imputations than would the type of weight adjustment procedure that is often used.

In addition to the bias reduction that may or may not result from the use of substitution, there are two advantages and three disadvantages that generally apply to substitution procedures. The two advantages are that (1) the sample will be balanced with respect to sample size per substitution class (this has practical advantages in self-weighting and two-per-stratum designs), and that (2) for a fixed initial sample size, substitution procedures increase the survey sample size and, therefore, reduce the variances of the survey estimates.

The first disadvantage follows directly from the second advantage, namely that an increase in the sample size generally involves an increase in the survey costs. The second and major disadvantage of the use of substitution is that the effort extended to obtain participation from originally selected units may not be as intense as it would have been if no substitutes were available. (Using the original units is always preferable to using substitute units, so steps should be taken in planning the data collection procedures to ensure that the maximum effort is made to obtain responses from the original sample units.) The third disadvantage is that there is a tendency to ignore the level of substitution used when the survey response rate is reported. Thus, whenever substitutes are used in a survey, the researcher must (1) keep accurate records of which units are substitutes, (2) identify which data records are obtained from substitute units, (3) report the level of substitution, and (4) treat the substitutes as nonresponse cases when calculating the survey response rate.

Chapman conducted an extensive search of the published and unpublished survey research literature. He was unable find any theoretical work relating to substitution, and he found only four studies involving empirical studies of the impact of substitution procedures on survey estimates. Only one of these four

studies included a comparison of the estimated effects (or biases) for a substitution procedure and the corresponding estimated effects (or biases) for one or more alternate imputation procedures. Unfortunately, the type of substitution procedure used in the comparative analysis was atypical and the scope of the comparisons was rather limited.

At this time, there are apparently no theoretical results available to evaluate the general usefulness of substitution procedures as methods for imputing for total questionnaire nonresponse. There appear to be some situations for which substitution procedures are appropriate, and other situations (surveys with large sample sizes and with relatively little information available about the nonresponding units) where substitution would be unwise.

Empirical investigations, of which only four are known, all seemed to indicate that substitution procedures do not eliminate the effects of nonresponse bias; one study indicated that there was consistently a negative 5% bias in a number of estimated totals that was attributable, to a large extent, to the use of substitute institutions and institution nonresponse weight adjustments.

The fact that substitution procedures do not seem to eliminate nonresponse bias does not imply that substitution procedures are inappropriate. Indeed, it is probably true that there is no procedure available that can adequately correct nonresponse bias; in a 1974 study, none of the six alternate weight adjustment procedures that were compared could correct the nonresponse bias associated with a number of items in a questionnaire.

The Bureau of the Census is planning a thorough empirical study to evaluate the usefulness of substitution procedures as part of a FY 1983 random digit dialing investigation. Prior to the release of this study, and based on the available information, DNRC plans to use specially designated substitutes to replace units in the original sample who absolutely refuse to cooperate with the commercial study and refuse conservation audits.

DNRC will use substitution only after extensive efforts have been made to obtain the nonrespondents' cooperation, and will keep extensive records of the substitution procedures used and the use of substitute records in analyzing the survey results.

REFERENCES:

The text of this appendix is a summary of a paper presented by David W. Chapman, the Bureau of Census, at the 142nd annual meeting of the American Statistical Association held in Cincinnati, Ohio, August 16-19, 1982. Chapman's paper, "Substitution for Missing Units," will appear in the 1982 Proceedings of the Section on Survey Research Methods of the American Statistical Association, and in the report volumes of the Panel on Incomplete Data, Committee on National Statistics, National Academy of Sciences to be published by Academic Press.

Kish, L. 1965. Survey Sampling, John Wiley and Sons, N.Y.

APPENDIX 5

PRELIMINARY ENERGY AUDIT DATA SHEET

STEP 1 OF PHASE I

I.D. ☐☐☐☐☐☐☐☐☐☐ FOR OFFICE USE ONLY

NOTE: Only one building or structure may be reported on a single form.

1 Name of Building

2 Street Address

3. Area Type (R - Rural, U - Urban)

4. City

5. County

6. State

7. Zip

8 Building Owner

9. Street Address

10. City

11. State

12. Zip

13. Building Energy Coordinator or Contact Person

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14. Region

15. Station

16 Do you intend to participate in the energy audit? (Y - Yes, N - No) Please send an Energy Audit contract.

17. Enter the code from the following list that best describes the building.

Schools
- Elementary ... 11
- Secondary ... 12
- College or University ... 13
- Vocational ... 14
- Local education agency administrative building ... 15
- Other (specify) ... 16

Hospitals
- General ... 21
- Tuberculosis ... 22
- Other (specify) ... 23

Local government buildings
- Office ... 31
- Storage ... 32
- Service ... 33
- Library ... 34
- Police station ... 35
- Fire station ... 36
- Other (specify) ... 37

Public care buildings
- Nursing home ... 41
- Long-term care — other than a nursing home ... 42
- Rehabilitation facility ... 43
- Public Health Center ... 44
- Residential child care center ... 45

18. Enter a code from the following list if the building is owned by one of the following.

- Public institution ... 1
- Private nonprofit institution ... 2
- Indian tribe ... 3

19. Enter the square footage of all heated or cooled floor areas enclosed in the building. Calculate square footage from the outside building dimensions, or from the centerline of common walls.

20. Enter the number of heated or cooled stories in the building.

21. Enter the code from the following list that best describes the building shape. (Looking down from above the building) 21 ☐

Square	1	H shaped	4
Rectangular	2	L shaped	5
E shaped	3	Other (specify)	6

22. Enter the code from the following list that best describes the roof of the building. 22 ☐

Flat roof	1
Pitched roof facing South	2
Pitched roof not facing South	3

23. Check the boxes that best describe any rooftop structures. 23

- Chimneys ☐
- Space conditioning equipment ☐
- Water towers ☐
- Mechanical rooms ☐
- Stairwells ☐
- Other structures (specify) ☐

24. Enter the year that the building was first placed in service. 24 ☐☐☐☐

25. From each of the following lists enter one code that best describes the building structure.

Foundation 25a ☐☐

Concrete	11
Wood	12
Stone	13
Concrete block	14

Roof b ☐☐

Wood shakes	21
Slate	22
Metal	23
Built-up	24
Asphalt shingles	25
Fibre glass	26
Felt	27
Decking	28

Floor c ☐☐

Wood	31
Concrete	32
Marble	33
Metal	34

Ceiling d ☐☐

Concrete	41
Metal	42
Sheet rock	43
Plaster	44
Open	45
Wood	46
Lay in	47

Interior Walls e ☐☐

Tile	50
Metal	51
Glass	52
Sheet rock	53
Brick	54
Block	55
Stone	56
Wood	57
Plaster	58
Concrete	59

Southern Exterior Walls f ☐☐

Stone	61
Brick	62
Concrete	63
Concrete block	64
Stucco	65
Wood	66

26. Enter the code from the following list that best describes what proportion of the southern facing wall is glass. 26 ☐

0 to 25 percent 1
25-75 percent 2
75-100 percent 3

27. Enter the approximate number of hours that the building is operated daily, including periods of partial use if applicable. 27 ☐☐

28. Enter the number of weeks per quarter that the building is in use. 28 ☐☐

29. Enter the code from the following list that best describes the type of heating system in the building. 29 ☐

Steam boiler(s) 1
Hot water boiler(s) 2
Modular steam boiler(s) 3
Modular hot water boiler(s) 4
Forced air furnace 5

30. Enter the code from the following list that best describes the type of fuel used to run the heating system in the building. 30 ☐

Electricity 1
Natural gas 2
Fuel oil 3
Coal 4
Propane 5
Butane 6
Other 7

31. If the building has a central air conditioning system, enter the code that best describes the system. 31 ☐

Electric reciprocating 1
Electric centrifugal 2
Absorption 3
Compressor driven by steam turbine 4

32. Enter the code from the following list that best describes how domestic hot water is heated. 32 ☐

Heated by electric heater(s) 1
Heated by gas heater(s) 2
Heated by oil heater(s) 3
Heat exchanger from the boiler(s) only source of domestic hot water 4

33. Check the boxes that best describe any special energy using systems in the building.

33
Food service .... ☐
Laundry service .... ☐
Computer .... ☐
Elevator .... ☐
Laboratory .... ☐
Library .... ☐
Other (specify) .... ☐

34. Enter the code from the following list that best describes any energy use study that has been conducted in the building. 34 ☐

Walk through energy audit covering operational and maintenance procedures by an auditor other than an engineer 1

Detailed energy use study conducted by an engineer 2

Detailed energy use study conducted by an engineer including feasibility of renewable energy systems (such as solar) 3

Other types of energy use studies (specify) 4

35. Enter the code that best describes the location of the heating system. 35 ☐

Outside the building 1
Within the building on the ground floor 2
Within the building in the basement 3
On the roof of the building 4

36. If the heating system is within the building, enter the code from the following list that best describes the type of heating system. 36 ☐

Centrally located 1
Multiple units 2
Central and multiple units 3

37. If more than half of the building's roof area or southern facing wall surface is heavily shaded by trees, buildings or other obstructions, enter the number of hours per day that these areas are shaded. 37 ☐☐

38. If unshaded open land such as fields, yards, parking areas etc. is available within the immediate vicinity of the building, list the approximate square footage of these areas. 38 ☐☐☐☐☐☐☐☐

39. If any major energy conservation measures have been implemented in the building, check the boxes that best describe the measures. 39

Wall or roof insulation . . . . . ☐

Storm windows . . . . . ☐

Air intake controls . . . . . ☐

Thermal drapes . . . . . ☐

Vestibule doors . . . . . ☐

Caulking and weatherstripping . . . . . ☐

Other (specify) . . . . . ☐

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DNRC COMMERCIAL SECTOR STUDY

ADDENDUM

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DNRC COMMERCIAL SECTOR STUDY ADDENDUM

Introduction

This paper is DNRC's response to the critical review by 20 professionals of the original commercial sector survey proposal. (See the appendix.) The points addressed fall into two major groups, dealing with the survey strategy itself, and with the proposed analysis of the survey data. Each major criticism is presented and discussed, and, where appropriate, recommendations for altering the survey strategy are made. The final section briefly summarizes the findings.

I. THE SURVEY

Variance and Precision Estimates

A common criticism of the proposal was that the level of accuracy used in the sample size estimates (80% confidence level) is not sufficient to provide meaningful results when generalizing the conservation results back to the population.

In order to obtain a test sample of the expected variance in the Montana commercial building population, a subsample of all Montana Power Company accounts that DNRC classifies as commercial were examined to find the mean electricity consumption and the sample variance. The mean consumption was only 70.44 MWh per year and the standard deviation was very high at 224.85 MWh. The coefficient of variation was 319.2 percent, indicating tremendous dispersion in the data. Since DNRC has only enough funds to study approximately 100 buildings, the statistical

measures of precision were varied to find the level of confidence at which the survey could be based. Unfortunately, as shown on page 8 of the original proposal, the indicated level is disappointingly low. At a poor 80 percent confidence level, over 40 percent error in the estimation of the mean conservation potential must be accepted. This result, along with other sources of cumulative error in the conservation estimates, would have a very detrimental effect on the accuracy of the final conservation estimates. More commonly acceptable statistical levels would consist of a level of precision of 10 percent, a 90 percent confidence level and, consequently, a risk of error of 10 percent. Based on these requirements, the calculation of sample size is:

$$n_o = \frac{1.65^2 * 50,557.5}{7.04^2}$$

$$n_o = 2,777$$

Since N is 18,144, n_o/N is greater than 10%, and the sample size is better approximated by:

$$n = \frac{n_o}{1+(n_o-1)/N}$$

$$n = \frac{2,777}{1+\frac{2,776}{18,144}} = 2,408$$

A sample size of 2,408, or 13 percent of the population, would be required. This is clearly beyond DNRC's resources for the study.

Much of the variance seen in such a sample occurs because use of energy as the dependent variable yields heteroscedastic variances in the residuals (Hirst et al., 1981). This simply means increasing variance is observed with increasing energy use. Therefore, DNRC examined methods to reduce the variance observed in the sampling population to raise the confidence levels of the study to a more reasonable level. Five methods have been examined for treating the commercial building data to reduce the variance. They are 1) developing an optimally allocated stratified random sample, 2) normalizing the consumption based on building floorspace, 3) normalizing the data based on heating degree days, 4) normalizing the data based on total energy consumption, and 5) separating buildings into two groups--those with energy use dominated by process consumption and those with consumption dominated by envelope loads.

In the stratification example used in DNRC's original survey paper, non-commercial SIC codes were not excluded, although all accounts with consumption under 3,000 kWh were deleted from the file. Censoring the lower consumption accounts deleted 11,214 files from the total 32,255 accounts while cutting off only 41,103 MWh from the total two million MWh consumed in the sector. This raised the mean consumption from 62.9 MWh to 94.5 MWh while reducing the coefficient of variation considerably. Using the simple random sample formula, the indicated sample size is 7,496 accounts, an indication of the variance reduction when non-commercial rate accounts are included (see previous page). However, this sample size is far too high to be reasonably attained, representing 36% of the available population of commercial-industrial accounts.

A survey of commercial buildings is an ideal situation for using stratified sampling since the measured electricity consumption varies widely with building size. Stratified sampling results in smaller variances within the strata relative

to the larger variances in the overall distribution. Sampling theory shows that, with a good stratification procedure, a sample of size n will result in a smaller variance for the estimated mean than a simple random sample of the same size. Optimal allocation schemes allocate the sample size among the strata in a way that minimizes the variance of the estimated mean.

Occasionally, when the overall sampling fraction is substantial and some strata are much more variable than others, the mathematical formula for optimal allocation may produce a strata sample size n_h larger than the corresponding strata population size N_h. When there are only two strata, the best solution is to sample the one stratum with certainty, leaving the remaining portion of the sample size for the other stratum. When there are more than two strata, revised optimal allocation formulas are used (Cochran, 1977).

In other cases, the researcher may determine that some strata should be sampled with certainty and the other strata allotted the remainder of the sample size. It is impossible to know if such procedures compromise optimal allocation unless intra-strata variances can be accurately determined.

Optimal allocation formulas rely on the knowledge of the within-strata variances, S_h^2. When these are unknown or cannot be accurately estimated, the optimal allocation procedures may be unworkable. For this reason, proportional allocation is used more often than optimal allocation (Williams, 1978). DNRC will resort to proportional allocation, as recommended by some reviewers, if there are practical problems with implementing optimal allocation, or if DNRC is uncomfortable with the pilot study variances.

The problem in stratified sampling with optimum allocation is determining intermediate stratum boundaries between the largest and smallest observed sample values such that the variance of the estimated mean is minimized. This problem is mathematically equivalent to minimizing the sum of the products of the strata weights and variances. Mathematically, however, the minimizing equations are ill adapted to practical computation. The Dalenius-Hodges procedure is one approximation technique which has been widely studied. In the usual case where stratifications must be based on a variable x somehow related to the variable y, rather than on the values of y itself (which would be the ideal situation), studies suggest that the Dalenius-Hodges procedure applied to x should give an efficient stratification for another variable y that has a high correlation with x.

It is possible to estimate the quantitative effect the increase in precision due to stratification sampling will have in terms of its effect on sample size. Table 1 below summarizes the data used in the Dalenius-Hodges procedure:

Table 1

STATISTICAL SUMMARY, MONTANA POWER COMPANY COMMERCIAL ACCOUNT DATA

Simple Random Sampling

$\overline{X}$ = 94,506.0 kWh

N = 21,041

Var. = $3.82 * 10^{11}$ kWh^2

St. Dev. = $6.18 * 10^5$ kWh

C.V. = 6.45

Total Consumption = $1.9885 * 10^9$ kWh

Three Strata

Stratum #	No. Accts.	Std. Dev. (kWh/year)	Variance
h	N_h	S_h	S_h^2
1	9,600	3,352.61	$11.24 * 10^6$
2	8,497	20,420.58	$4.17 * 10^7$
3	2,944	1,579,240.30	$2.494 * 10^{12}$

Four Strata

Stratum #	No. Accts.	Std. Dev. (kWh/year)	Variance
h	N_h	S_h	S_h^2
1	7,005	1,970.03	$3.881 * 10^6$
2	8,081	8,232.86	$67.78 * 10^6$
3	3,922	27,000.0	$7.29 * 10^8$
4	2,033	1,868,154.2	$3.49 * 10^{12}$

Five Strata

Stratum #	No. Accts.	Std. Dev. (kWh/year)	Variance
h	N_h	S_h	S_h^2
1	6,335	1,685.23	$2.84 * 10^6$
2	5,028	2,851.32	$8.13 * 10^6$
3	5,822	13,275.92	$1.76 * 10^8$
4	2,472	35,355.34	$1.25 * 10^9$
5	1,384	2,215,852.0	$4.91 * 10^{12}$

We assume a level of precision of ± 10% and a 90% confidence level. Therefore, a sampling distribution is required that has a standard error of:

$$\sigma_{\hat{Y}} = \frac{(.10)\ (1.9885 * 10^9)}{1.65}$$

$$= 1.205 * 10^8 \text{ kWh}$$

Accordingly the variance is:

$$\text{Var }(\hat{Y}) = \sigma_{\hat{Y}}^2$$

$$= 1.4524 * 10^{16} \text{ kWh}^2$$

From this, the simple random sample size is calculated:

$$n = \frac{N^2\ S^2}{\text{Var }(\hat{Y}) + NS^2}$$

$$n = 7{,}496$$

The number of accounts in each stratum are allocated with Neyman allocation so that:

$$n_h = \frac{n\ N_h\ S_h}{\Sigma\ N_h\ S_h}$$

This can be incorporated into the sample size calculation to test the efficiency of the stratified sample versus the simple random sample:

$$n = \left(\Sigma\, N_h S_h\right)^2 \quad \left(\mathrm{Var}(\hat{Y}) + \quad \Sigma\, N_h S_h{}^2\right)^{-1}$$

Using the data from Table 1, we calculate n to be 1,078 for the three strata design, 734 for four strata and 497 for five strata. This represents a reduction in the indicated sample size by more than an order of magnitude. Consequently, a significant reduction in the variance of DNRC conservation estimates can be expected from the demonstrated efficiency of the optimally allocated stratified sampling technique. However, the required sample sizes are still excessive, given DNRC's budget.

Each of the three strategies based on normalizing the consumption data has the distinct disadvantage of requiring data on the normalization characteristic in order to generalize the conservation estimate back to the population. Data on these characteristics is not contained in the Montana Power commercial accounts file. However, DNRC maintains a file of 722 commercial buildings in its Institutional Buildings Grants Program (IBGP) file. A random sample of fifty buildings from this file was used to check how the IBGP data compared with the MPC data and to test the various variance reduction strategies. As one might expect, the IBGP data is skewed toward larger consumers (schools, hospitals, and local government buildings). The mean electricity consumption was 222.35 MWh; the standard deviation was 239.67 MWh for a coefficient of variation of 107.8 percent. The IBGP consumption data show less variability than the MPC account data. However, it is possible to use this information to examine the variance reduction strategies. Application of the random sample size equations show that 220 buildings of the IBGP stock would have to be

sampled to achieve a 90 percent confidence level and a level of precision of 10 percent. Table 2 summarizes the statistical data taken from the 50 unit IBGP sample:

Table 2

ANNUAL ENERGY USE IN 50 IBGP BUILDINGS

	Ft^2	MWh	$EBtu/ft^2$	$EBtu/ft^2/HDD$	$TBtu/ft^2/HDD$
Mean	42,124.4	222.35	20,926.88	.79	15.94
Std. Dev.	38,607.4	239.67	13,016.35	1.3184	9.67
Var.	1.49×10^9	57.44×10^9	1.69×10^8	1.7381	93.44
C.V.	91.7%	107.8%	62.2%	60.1%	49.1%

Notes: EBtu = Electricity Btu
TBtu = Total fuel Btu
HDD = Heating Degree Days
CV = Coefficient of variation = σ/μ = $\sqrt{\text{relvariance}}$

Performing the sample size calculation for the consumption in terms of electrical Btus consumed <u>per square foot</u> drops the sample size to 92. Normalizing by both square footage and heating degree days drops the sample size slightly more to 86. Finally, normalizing by square footage, heating degree days and total energy use drops the required sample size to 60. Further, if a level of precision of 15 percent can be tolerated, the sample size drops to only 29 for the IBGP data. These efforts represent a significant reduction in sample size, while preserving the statistical integrity of the methods. However, because the IBGP data is more homogeneous than the MPC accounts and not a random sample of commercial buildings, DNRC should still plan to draw as large a sample as it can afford.

The greatest variance reduction results from using square footage information and consumption data for other fuels to normalize the data. In order to generalize from the conservation estimate obtained from the survey, information on floor space

and/or fuel shares in the population would be necessary. Since the variance in the commercial square footage data in Table 2 is quite large, the 100 audit surveys will not be sufficient to provide this information. Two suggested approaches are presented for this problem. One would be to do a larger (500-1,000) sample by phone or mail of the MPC acounts to obtain square footage information, and later draw the buildings to be audited from that initial sample. Another would be to use the Montana Employment Security Division's information on building square footage and employee data to develop two digit SIC correlations of commercial employees and building square footage. This could be used in conjunction with the very complete county census data for Montana employees to predict service area floorspace areas. These correlations could be checked by application to data collected from the audited buildings to evaluate their predictive accuracy. Unfortunately, the latter method has the added difficulty of requiring separation of the MPC service area from that of other utilities in each county. This could be accomplished through weighting of the relative number of commercial accounts in each utility within the counties to apportion the floorstock attributable to Montana Power accounts. Overall, the accuracy of this method would not be as great as the sub-sampling approach and could cost substantially more.

The fuel share also can be collected as part of an initial phone or mail survey. However, data quality might be poor since fuel use is not as easily defined or as readily available as is square footage.

The heating degree day information is readily available by zip codes for Montana. Data on climate will be collected for each site in the audit. The explanatory power of this variable is considerably less than the previous two factors, fuel mix and square footage.

A final strategy would involve post survey separation of the audit into two groups. One would consist of buildings with energy loads that are dominated by process related activities, such as restaurants and grocery stores, and the other would consist of buildings that are dominated by the building envelope, such as small offices and schools. These two groups use energy very differently and treating them separately during the analysis should produce further reductions in variance. Since there is no data available on process dominated buildings, it is impossible to know how productive this strategy might be until the sample is drawn.

The Prototype Approach

DNRC has examined the prototype approach as an alternative to the proposed survey strategy. Briefly, this method consists of locating a number of buildings that are believed to be representative of those housing a particular commercial activity and performing a computer analysis of the conservation potential on these buildings. The amount of commercial floor stock represented by a particular building type is then used to generalize the conservation estimates to the population at large. The technique's primary advantages are its lower cost and its use of detailed engineering audits as inputs to the simulation process. Also, prototypes usually can be found in an area conveniently located for the study team. DNRC finds the following disadvantages to the prototype method:

1) Little information exists on the systematic bias that may result from the building selection process. It is impossible to evaluate the degree to which the prototype represents the population. Since there is no analytic method for quantifying the magnitude of this error, there is little indication of how correct or incorrect the estimates may be.

2) The results of the simulation analysis are usually generalized linearly back to floor space estimates. Such linear estimates assume a normal distribution of floorspace and energy consumption (C. H. York and Associates, 1983). DWRC has found floorspace and consumption to be positively skewed and possibly log-normal in nature. Since the mean and median values in a geometric distribution may be widely separated, a "typical" building may vary significantly from the mean.

3) Prototype buildings do not evidence any of the considerable variability that may exist within a single building type. Coefficients of variation of 50-70 percent are commonly observed in the buildings' energy consumption normalized by floorspace. This represents a very large source of cumulative error that is often ignored by users of the prototype technique.

It is possible that the increased simulation accuracy and cost advantage of the prototype approach are more than offset by sources of systematic error that are impossible to measure. Paradoxically, this error may represent the method's chief analytic appeal. It is difficult to criticize the prototype based results, especially for the commercial sector, since they are based on a series of non-parametric assumptions.

Consumption Cut-off Points for the Survey

DWRC will define consumption cut-off points in the sampling scheme to eliminate non-building commercial accounts on the low end of the population such as phone

booths, billboards and so forth, and to delete as many of the small industrial accounts as possible on the high end of the consumption scale. The goal of this procedure is to reduce overall sampling variance as much as possible, while excluding non-commercial accounts and non-building commercial activities.

Based on comments from three utilities, the high and low survey sampling cut-off points used as examples in the proposal will exclude a significant number of real commercial accounts. All comments have indicated that such cut-off points will not be well defined in actual practice. In Appendix 2 of the survey paper, hypothetical low and high cut-off points of 3 and 150 MWh were used. The example's high point is certainly too low. A typical all-electric fast food restaurant will use 400 MWh year and legitimate commercial accounts may go up to 5,000 MWh. A low consumption cut point of 3-5 MWh has been suggested by a utility as being a level below which commercial buildings' activities are negligible.

Application of these boundaries to the commercial sector account file (<5,000 MWh) would delete the top 43 accounts and almost 13,000 of the low consumption accounts (< 5 MWh). However, the actual points will have to be ascertained from the data itself. As mentioned in the original study proposal, it is very possible that no realistic cut-off points will be discovered in the account file.

Similarly, excluding accounts that are classified as industrial for rate purposes will likely result in missing real commercial accounts. Industrial rate classifications often include important components of the commercial sector such as hospitals and university campuses.

Even if realistic sampling cut-off points are not evident from the MPC data, it is possible to arbitrarily create such points through sampling a portion of the population with certainty. Since much of the sampling variance lies in the very high consumption accounts, it is desirable to remove as many of these from the sampling procedure as possible. Although these accounts range in consumption as high as 35 million kWh, they are not very numerous. Out of the 21,041 accounts, there are only 95 that are greater than two million kWh. If all these 95 accounts were sampled with certainty in the supplementary sampling procedure, it would be possible to arbitrarily establish this as a cut-off point.

An analysis of the stratified sampling procedure applied to commercial sector study has shown the use of such a certainty group to have a very beneficial effect on the precision of the estimates (ADM Associates, 1982). Although DHRC found ADM's test population to contain less dispersion and skewness than actual commercial utility data, this does not seem to alter this finding. Thus, sampling with a certainty group seems to be the preferred option in the likely event that a high consumption cut-off point is non-existent. This, of course, could have some impact on the allocation strategy.

Preference for Phone Survey as Opposed to Mail Instrument

Based on past experience, three reviewers recommended phone surveys for all supplemental sampling necessary in the study. Reasons given included both cost and effectiveness. In addition, other reviewers mentioned poor experiences they had in the past with mail surveys. The only reviewer who advocated mail surveys noted that its use would necessitate an initial phone contact to produce an acceptable response level. Consequently, phone surveys for supplemental sampling would seem to be indicated.

Utility Account Duplication

Account duplication is a serious bias problem in a utility sampling strategy. Businesses or institutions with two or more accounts for the same building are more likely to be selected into the sample than those with only one account. Furthermore, based on the experience of Pacific Gas and Electric and Seattle City Light in their commercial sector surveys, the number of duplicate accounts tends to increase with the larger consumers. The planned stratified sampling approach would, therefore, find relatively more of these duplicate accounts since the larger consumption strata are sampled at a higher rate.

In the original paper, DNRC proposed that a computerized name and address matching system be used to identify the duplicate accounts. The methodology used will probably be based on that created for Pacific Gas and Electric (Minimax, 1981). According to the experience of that utility, it is expected that such a system is at best only about 80 percent successful. In the remainder of the duplicate accounts, the addresses or names cannot be matched or may be mismatched by the computer. It will be possible to scrutinize the final selected accounts by hand so that no duplicates will be chosen; however, some duplicate accounts will remain in the sampling procedure itself. DNRC believes that the matching system will reduce the magnitude of this potential problem to acceptable levels. Considering the immeasureable bias introduced by an unknown number of duplicate records altering the assumed probability of selection, increasing the quality of the sample frame is preferable to increasing sample size. Therefore, any moderate increase in funding for the proposed study will be used to remove as many duplicate records as possible from the MPC account file.

Specifics on Field Data Collection

One serious omission in the survey proposal is the necessity of collecting field data on consumption of all fuels in both the audit and supplemental surveys. This is very important to the later simulation analysis of the building's energy consumption, since electricity conservation can increase the consumption of other fuels. Information on all fuel types used in the building will be collected and used for the energy simulation analysis.

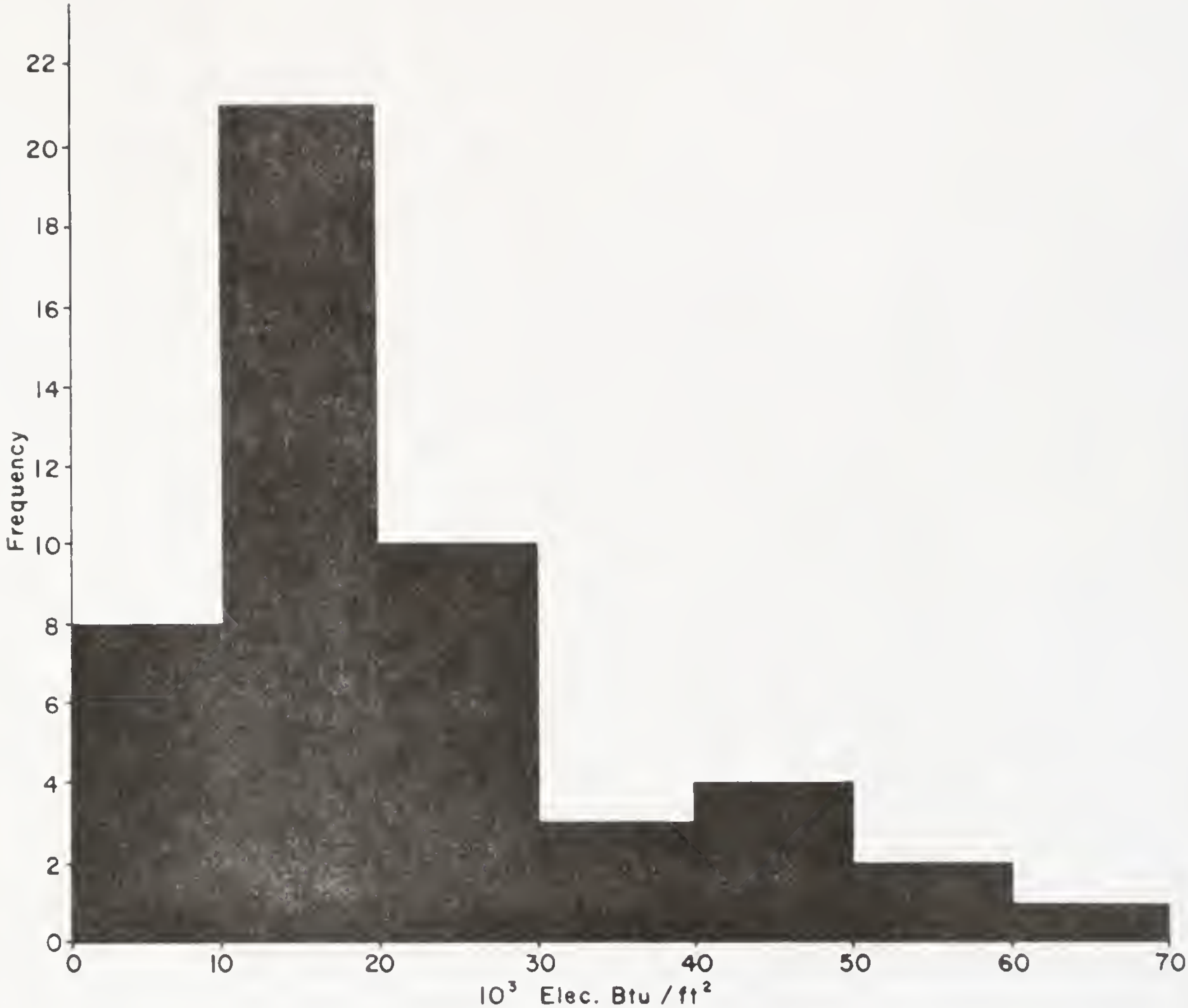
Normality of Commercial Building Energy Consumption

In studying Montana commercial sector buildings, DNRC has observed a non-normal frequency distribution of area dependent energy consumption. The fifty unit IBGP sample showed a significant positive skewness in terms of electricity consumption normalized by square footage. The resulting frequency distribution is depicted in Figure 1.

The Pearsonian coefficient of skewness was 1.134, indicating a distribution strongly skewed toward the lower consumption. Additionally, the data has the appearance of a log-normal or bi-modal distribution. Since the IBGP sample is less heterogeneous than the Montana Power account file, it is difficult to know how this data will relate to the information actually collected in the sample.

Figure 1

IBGP BUILDINGS ENERGY FREQENCY DISTRIBUTION



An examination of the non-normalized MPC commercial account data also showed it also to be highly skewed. Conservatively deleting all accounts below 3 MWh per year, the Pearsonian coefficient of skewness was .922, indicating a strong positive clustering in the low consumption accounts. Furthermore, utilization of Davies test of skewness (Davies and Crowder, 1933) indicates a logarithmic distribution. In the 21,041 accounts, the quartile values were:

Lower quartile = 5,487.9 kWh

Middle quartile = 17,349.2 kWh

Upper quartile = 32,386.9 kWh

In the Davies test, if values less than +.15 result, a logarithmic distribution is indicated:

$$\frac{(\ln LQ + \ln UQ) - (2 * \ln MQ)}{\ln UQ - \ln LQ} = -.297$$

This geometric distribution of the population may have important implications for the overall conservation assessment and its accuracy. It may be that best statistical estimates result from consumption transformed to natural logarithms so that the distribution of the random variable is approximately normal.

II. ANALYSIS

Cost of the Audits and Analysis

Several reviewers noted that the $1,000 cost for each building audit and analysis seemed low. However, a recent study found the average cost of a detailed

commercial walk-through audit to be about $600 (Gorzelnik, 1983). The $1,000 audit/analysis estimate is based on several assumptions:

1) The audits will be confined to several relatively compact areas that exist along a specific travel route. The Montana Power Service area is more or less confined to the more populated areas of western and central Montana, and the stratified sampling approach will tend to select larger consumers which will usually be located in the major population areas within the state. DNRC may consider replacement of some units chosen from outlying regions, since every thousand dollars spent on travel expenses will reduce the sample size by one percent.

2) Auditors will be provided with a list of the buildings, an itinerary, addresses and phone numbers, and also the utility energy consumption records for the building before the on-site visits. Consumption waivers will be obtained and phone contacts made prior to the visits.

3) The audits will be extensive, but not as detailed as required for an hourly simulation program such as DOE-2. A more general, simplified computer program will be used that has less data requirements to run the simulation. Even so, detailed information will be collected on process uses of energy which are expected to be important in the analysis of conservation potential.

Audit Detail and Simulation Accuracy

Based on the level of audit possible for $1,000, the maximum realizable accuracy level of building simulations cannot be expected. The DNRC conservation analysis

will use abridged engineering data for the audited buildings in a simplified computer program. The maximum accuracy possible in commercial building simulations is ± 10 percent (Wagner and Rosenfield, 1982), so that the level reached by the DNRC study is apt to be considerably less, probably ± 20 percent. This will tend to somewhat increase the cumulative uncertainty in final conservation estimates. Nonetheless, the DNRC project will be one of the few studies that has attempted to quantify the accuracy of its conservation estimates. Most other studies are based on prototypes and, therefore, the estimates cannot be verified.

Model Validation and Calibration

The model must be able to demonstrate agreement with the DOE-2 program on a reference building and be able to track the results of that code over a range of input variables. This will be a specific task to be addressed in the contract for the study.

The simulation model must be calibrated against the utility bills for each audited building in order to provide consistent results in the conservation analysis. Data on all fuels used in the buildings will be available so that interactions between electricity and other fuel use can be accounted for in the conservation analysis.

Responsiveness of Conservation to Energy Costs

The electricity conservation potential calculated in the study is a point estimate which is applicable only to the year of collection. The estimate will be

in relation to the levelized costs of electricity from the proposed Salem plant. For purposes of the analysis, DNRC will assume that the power company will be able to purchase all cost-effective conservation. This sets conservation on an equal footing with generating resources, and avoids questions of consumer behavior and rates of market penetration. For estimates to be projected into the future, the conservation estimate would have to be incorporated into the MPC commercial forecasting methodology. Measures of demand elasticity in conjunction with predicted energy prices would be needed to provide this capability.

Further Analysis of the Data

Although not specifically described in the study proposal, other types of analysis are planned for the carefully collected DNRC commercial sector data. Among the most important of these will be a rigorous multiple linear regression model to attempt to identify key factors associated with both electricity and total energy consumption in commercial buildings. Such a regression will include variables for floor area, energy price, building vintage, occupancy, heating degree days, ownership, fuel mix, and a series of dummy variables to account for missing data elements. This would be similar to the successful study by the Minnesota Energy Agency. This study found energy price, building type, age, and occupancy to have significant explanatory powers in predicting commercial building energy consumption.

III. RECOMMENDATIONS

The DNRC commercial sector survey and electricity conservation analysis are faced with a series of very difficult statistical problems. In spite of limited funds and a highly variable population, reasonably accurate estimates of energy conservation potential must be obtained.

A short mail or phone survey of this sector will not allow collection of sufficient information in the detail or accuracy required to perform an adequate estimate of conservation potential. Such methods are apt to introduce considerable non-response bias since data vital to computer simulation will likely not be provided. Also, since mail and phone surveys of the commercial sector typically have low response rates, the nonrandom pattern of the returns would introduce more bias. However, such methods may be highly beneficial for supplemental sampling to gather limited data.

A prototype estimation strategy could be used to collect the types of information necessary to run commercial building computer simulations for the conservation assessments. However, this technique chooses the prototype buildings based on subjective "professional engineering judgment." Consequently, there may be serious fundamental problems with the representativeness of these buildings to the actual population. It is difficult to criticize the overall accuracy of these measures because the relationship of the buildings selected to the population is unquantifiable.

DNRC believes that a sample design incorporating stratification is the most efficient use of the available resources to gather the survey data necessary to estimate the electricity conservation potential in the MPC service area.

To increase the effectiveness of the stratification, DNRC will base its stratification on electrical energy consumption per square foot rather than on the unadjusted annual consumption. DNRC believes that consumption per square foot is more highly correlated with conservation potential than is unadjusted annual consumption. The use of consumption per square foot will help to eliminate from the

variance the spurious effect of larger businesses using more electricity due to their larger building size. Consequently, a significant increase in the accuracy of the survey estimates can be achieved through such normalization.

The difficulty with using consumption per square foot is that square footage is not available from the MPC account data used as the basis for the sample frame. DNRC plans to obtain this data with a supplemental survey. After narrowing the account file where possible by removing certain high and low consumption records as explained in the original proposal, DNRC will draw a sample of approximately 1,000 units from the remaining records. These units will be drawn systematically to insure that the full range of consumption values is observed. DNRC will then obtain the square footage of these businesses by conducting a phone or mail survey; by consulting existing administrative records available at county assessors' offices, the Department of Revenue, the Department of Labor and Industry, or the IBGP files at DNRC; or by retaining persons either to measure the actual square footage or to determine the perimeter characteristics of the business in order to calculate the approximate square footage.

The data from the sample of 1,000 businesses should give DNRC what it lacks now: a pilot study of the commercial sector.

Electrical consumption per square foot should fall into distinct subgroups within the major categories of (1) envelope-dominated vs. process-dominated businesses, (2) electrically heated vs. gas heated businesses, and/or (3) building characteristics and use, such as office buildings, warehouses, hospitals, and so forth.

If no clear pattern in annual consumption can be seen in the consumption per square foot data, DNRC can proceed by taking a simple random subsample size of 100 of these 1,000 records and using the audits of these 100 businesses and, poststratifying the results if necessary, determine an estimate of the conservation potential in the sampled population.

If, on the other hand, patterns in the consumption per square foot data can be translated into recognizable patterns in the unadjusted annual consumption data, DNRC can use this pattern to create strata, allocate the total sample size in terms of the MPC account information, and then draw the 100 businesses to be audited. This should yield a substantial reduction in the variance. Further reductions in the variance may be achieved through establishment of consumption cut-off points, sampling of upper end accounts with certainty and statistical estimation of the frequency distribution of energy consumption. Finally, the conservation results will be generalized to the population based on the consumption per square foot data gathered in the pilot survey.

While the DNRC survey approach may result in final conservation estimates with wide confidence intervals, we believe this method is more defensible than other commonly used approaches.

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APPENDIX

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